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CONTENTS.

CORRIGENDA.

In Vol. LI, page 586, 7th and 8th lines *transpose* with 9th and 10th lines, so as to read

"Rawle, subsequently the first president of the Historical Society of Pennsylvania, Thomas Jefferson, Alexander James Dallas, Isaiah Thomas, the founder in 1812 of the American Antiquarian Society of Worcester, Massachusetts, the Abbé Correa de Serra, David."

In Vol. LII, page 218, insert after the 1st line the 7th line from the bottom of the page.

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PLACE AND PERSONAL NAMES OF THE GOSIUTE INDIANS OF UTAH.

BY RALPH V. CHAMBERLIN.

(*Read January 3, 1912.*)

The Gosiute Indians of Utah have for many years been peacefully settled in two main colonies in Tooele County, one in Skull Valley and the other near Ibapa in the Deep Creek Valley. While the Skull Valley and the Deep Creek bands were parts of one tribe and had almost continual intercourse, their separation was sufficient to permit certain slight dialectic differences in language to arise, as the writer has elsewhere pointed out.[1] They are at present without any definite tribal organization and so reduced in numbers as to represent a mere remnant of the former tribe. That the dwindling in their numbers during the last half century has been excessive appears evident from the figures given in various early reports and the information obtained from the first white settlers of the region; and at the present time, in the two bands there are under two hundred souls, of whom, furthermore, a considerable number have been taken in from other tribes through marriage or otherwise. The old men weep at the doom of extinction which they believe plainly to see ahead of their people.

[1] "Animal Names and Anatomical Terms of the Gosiute Indians," *Proc. Acad. Sci. Phil.*, 1908, p. 75.

The Gosiute at present are essentially self supporting. They engage in agriculture, raising especially oats, wheat and hay with some garden truck. The land, until very recently, was divided up and worked by the individuals or families separately; but in the Skull Valley colony it is now worked in common under the direction of a superintendent appointed a short time ago by the Government. A school has also been established among them. Especially during the haying season, the men hire out as hands on the neighboring ranches. Occasionally they take contracts for getting out timber from the mountains for fence posts, fuel or other purposes.

Much of what was distinctive of the original Gosiute is fast passing away and in a few years will be forever beyond reach of the investigator. This fact becomes well impressed upon the mind of the person who has occasion in his inquiries to contrast the knowledge and point of view of the old men and women with that of the members of younger generations whose memories do not run back to the time before white dominance in the region and the new mode of life consequent upon it.

Place Names.

The territory formerly claimed by the Gosiute is arid and desolate, only a small portion of it even today having been reclaimed by irrigation. It was because of this generally desert character of the region that the name Gosiute came to be applied to the tribe, the word—in its etymologically more correct form *Kutsipiutsi* or *Gutsĭpiutsi*, whence *Gosiutsi*—meaning literally "desert people."[2]

[2] *Kutsip*, primarily ashes and secondarily parched or desert earth, + *iutsi*, people (*-iu* + nominal ending *tsi*). The Gosiute speak of themselves simply as *niu*, ordinarily without special ending, the *n* here being probably the pronominal indicative of the first person. They also use *ni'wina* with a similar force; but this word seems often now to be applied for Indian in general as contrasted with other races.

It may be mentioned here also, that the usual explanation of the name Paiute as meaning "Water Ute" (pa, water) is probably erroneous. There is a well-defined tradition among the Shoshone of a time when they formed one people with the Ute, Paiute and other basin tribes and bands. The explanation given the author is that at the time of the breaking up, one band that went off to the South was very large and hence was given the name of "Big People," *Pia Uta*, whence *Paiute*.

As a consequence of this sparsely settled condition of the country recognized English names have been applied to but few of its varied parts and features. Furthermore, the region has not been completely surveyed and no map that is not manifestly inaccurate in details, so far as such are represented, as yet seems to exist. Hence there appear two difficulties in the way of presenting a thorough account of the ethnogeography of the Gosiute; firstly, an account with English equivalents of place names must necessarily be much restricted by reason of the limited number having such equivalents, and, secondly, the indication of places, etc., by means of map is not possible in the absence of survey and detailed map of the region involved. These difficulties have discouraged the writer from a plan to prepare an exhaustive account with maps showing trails, important camping points and other places and features formerly of significance and interest to this people.

It will be seen that in the place names listed below certain words recur frequently in combination. When one considers the character of the country and climate and the consequent preciousness of water, one will readily understand why in the majority of these names there is in combination some such word as water, spring or creek. These and some other words common in the names with their meanings are as follows.

1. *pa* (*ba*), meaning water.
   Examples: *Ai'bĭm-pa*, "Clay water," Ibapa.
   So'ni-ba, "Grass water," St. Johns.
2. *o'gwût* (*o'gwa*, *o'ga*), meaning river, stream or creek.
   Examples: *Pi'o-gwût*, "Big River," Jordan River.
   So'ho-gwût, *So'ho-gwa*, "Cottonwood Creek," City Creek, Salt Lake Co.
3. *pa'roi-kĭn*, meaning spring. This word is composed of *pa*, water, and *ma roi' kĭn*, to arise or ascend.
   Example: *Ku'nĭ-gi-pa-roi-kĭn*, "Fire spring," a spring in Skull Valley.
4. *pa'rĭ-tsi*, *pa'rĭ-tsi-ûp* (*pa'-tsi-ûp*, *pa'tsûp*), also meaning spring. The word is composed of *pa-ri*, referring to water (adjective form), *tsi*, meaning secondarily to squeeze or ooze out from, etc., and in the full form, *up*, nominal ending.

Examples: *Pi'a-pa-ri-tsi-pa,* "Big Spring Water," Big Springs in Skull Valley.
Päñ'gwi-ba-dsûp, "Fish Springs," Spring Creek.

5. *bai'gwi-ci,* meaning, apparently secondarily, stream or torrent (*bai'gwi,* to swell. Cf. also *bai'gwi,* blood vessel).
Examples: *Añ'go-bai-gwic,* "Spruce stream," Muddy Creek.
Pi'a-bai-gwi-ci, "Big Stream," Big Cottonwood Creek or Canyon.

6. *pa'ga-ra, ba'ga-ra,* meaning lake or sheet of water.
Example: *Pu'hu-i-ba-ga-ra,* Hot Spring Lake.

7. *o'nû-pi, o'no-pi,* meaning hollow or gulch, mud-flat, etc.
Examples: *Tsi'a-pa-o-nû-pi,* "Dry Gulch or Canyon," a gulch east of the Indian ranch in Skull Valley.
Bi'cûp-o-nû-pi, "Paint gulch or canyon," Mercur.

8. *so'kûp,* meaning earth.
Example: *Ăñ'ka-so-kûp,* "Red earth," Parley's Canyon.

9. *toi'ya-bi* (*roi'ya-bi*), meaning mountain.
Examples: *Pi'-a-roi-ya-bi,* "Big mountains," Deep Creek Mountains.
Pu'i-toi-ya-bi, Pi'a-roi-ya-bi, "Duck Mountains," Goose Valley Mountains.

10. *ga'ri,* mountain range, mountain.
Examples: *O'ga-ri,* "Wood Range," Oquirrh Mountains.
Yïn'ûn-ga-ri, Porcupine Mountains.

11. *hna, na,* a suffix added to words to signify a camping place or settlement. The root *na* means primarily to grow up, to rear (cf. the reduplication (*ma*)*na'na, ma na'hna,* to rear, to raise, to bring up).
Examples: *To'a-hna, To'a-na,* "Pipe Camp," Toana Springs.
Pa'u-hna, "Sea-gull camp or breeding place," Bird Island on Great Salt Lake, where the sea-gulls nest in great numbers.

In addition *ûp*(*-p*), *bi,* and *ts* or *tsi* as common nominal suffixes the meanings of which the author has elsewhere explained, may be noted.

In names compounded of two nouns *m* or *n* is frequently added

to the first, which position the one having the attributive relation always occupies.[3]

The alphabet of the American Bureau of Ethnology is used in the spelling of all Gosiute words in the present paper.

Ai'ba-pa. See *Ai'bim-pa,* the preferable form.

Ai'bĭm-pa. Deep Creek, Tooele Co.

The word is formed from *ai'bi,* clay, + *m,* adjectival ending, + *pa,* water.

The town Ibapa in the Deep Creek Valley takes its name from this word.

Ai'bĭm-pa-ku-na-gûnt. Garfield, Tooele Co.

From *ai'bĭm-pa,* clay water, + *ku'na-gûnt,* in reference to the smelters located at this place (*kun,* fire, + *gûnt*).

Ai'bĭ-tci. Payson, Utah County.

Ai'bĭ-to-o-gû-pi. Pole Canyon, Tooele Co. (Deep Creek region).

An'da-pa. Burnt Spring, Skull Valley, Tooele Co.

Añ'go-bai-gwĭc. Muddy Creek, Deep Creek district, Tooele Co.

Añ'go-bi, spruce, + *bai* (prob.), signifying abundance, abounding in, + *bai'gwĭc,* stream.

Añ'go-ga-ri. Portion of Stansbury Range of Mountains, Tooele Co.

From *añ'go-bi,* spruce, + *ga'ri,* mountain range.

Äñ'ka-pĭ-tci. Hot Sulphur Springs.

From *äñ'ka-bĭt,* red, + *bĭ'tci,* milk or sometimes other liquids, here applied to the colored water of the springs (cf. the next word).

Äñ'ka-bĭ-tĭm-ba. Same place as preceding.

From *äñ'ka-bĭt,* red, + *ĭm* + *ba,* water.

Äñ'ka-ho-nûp. Echo.

Äñ'ka-bit, red, + *o'nû-pi, ho'nûp,* hollow, etc.

Äñ'ka-so-kûp. Parley's Canyon, Salt Lake Co.

From *äñ'ka-bĭt,* red, + *so'kûp,* earth, a name given in reference to the red color of rocks and soil of the mountains at the mouth of this canyon.

[3] See for further discussion of word formation in the Gosiute language the author's "Ethno-Botany of the Gosiute Indians," *Memoirs of the American Anthropological Association,* Vol. II., Pt. 5, p. 352 et seq.

Äñ'ka-ti-ban-o-gwû-pi. Thoms Creek, Deep Creek district, Tooele Co.

From *äñ'ka-bĭt*, red, + (prob.) *ti'ba*, pinenut, nut pine, + *n* + *o'gwû-pi*(*o'gû-pi*).

Äñ'ka-wi-a. Dugway, Tooele Co.

From *äñ'ka-bĭt*, red, + *wi'a*, trail, way, road. Cf. *Tsau'ga-toi-ya*, which is synonymous or apparently almost so.

Äñ'ko-gwa, Äñk'o-ga. Evanston, Wyoming.

Äñ'ka-bĭt, red, + *o'gwa*, river.

A'pa-ya-wi-ûp. Name for extreme southern portion of Oquirrh Mountains or west slope of same. The name is given to this section as the scene of a very disastrous and long drawn out conflict between the Gosiute and another Indian tribe, which one the author has been unable to make wholly certain. The name means in effect "Place of the weeping or wailing of ancestors," the caves in the neighborhood being supposed to be haunted by the shades of those who met death here. Cf. *I'djû-pa-ya-wi-ûp*, the same place but not the usual designation or the more correct, as *I'djûp* properly refers to the very first members of the human race when used in this sense, while *a'pa* refers more generally to less remote ancestors.

A'o-gwa. Butterfield Creek, Salt Lake Co.

From composition the name would seem to mean "Horn Creek" but *a* may here be representative of some other word not recognized.

A'rĭm-pi. Dugway Mountains.

Bi'cûp-o-nû-pi. Mercur.

"Paint Hollow" is the meaning of this name, the Gosiute formerly having obtained one of their face paints in this region.

Ĭ'djĭ-pa, ĭ'dji-pa. One of the streams north of Ogden. Probably "Coyote Creek or water."

I'djû-pa-ya-wi-ûp. Same as *a'pa-ya-wi-ûp*, which see.

Ka'na-ba-ho-nû-pi. Sandy, Salt Lake Co.

Ka'na, perhaps representing *ka'na-gwa-na*, Œnothera or evening primrose, + *pa'ho-nû-pi*, mud flat or hollow where water gathers; thus "primrose flat."

Kĭ'bĕ-ra-ga-ri. Snow Mountain.

Kĭ'ber-ant, high, + *ga'ri*, mountain.

Ku'i-o-gwa, Ku'i-o-ga, Kwi'o-gwa, Bear River. Also occasional for Evanston, Wyoming (see *Äñ'ko-gwa*).

From *ku'i*, a plant, + *o'gwa*, river.

Ku'nĭ-gi-pa-roi-kĭn. Small spring and creek north of Indian ranch in Skull Valley, Tooele Co.

From *ku'nĭ-gi*, pertaining to fire (*kun*, fire), + *pa'roi-kĭn*, spring.

Kwi'nĭn-gar-ni. Eagle Mountain, Idaho.

From *kwi'ni, gwi'ni*, eagle, + *n* + *gar'ni*, house. So called because many eagles formerly nested on the mountain.

Mo'ko-ga-ri. Granite Mountain.

Mo'ko-mom-bĭtc. Fremont Island, Great Salt Lake. *Mom'bĭtc*, owl.

Mo'ni-wai-ni. Red Butte Canyon.

The name refers to an occurrence after a battle, the hands of certain captives having been cut off and hung up at the mouth of this canyon seemingly as a warning against trespass.

Nai'ca-wi-o-gû-pi. Willow Creek, Tooele Co. (near Grantsville).

Na'na-wĭnt-a-ho-nûp. Birch Creek, Deep Creek district, Tooele Co.

Na'na-wĭnt, ascending, high, + *o'nû-pi*, gorge.

O'a-dĭ-tsĭm. A mountain in Skull Valley region; occasionally applied to the one more usually termed *To'go-a*, but probably through error.

O'a-pi. Dutch Mountain, Tooele Co. (Deep Creek district).

O'a-ta-kûn-ba. Drum Mountain, Tooele Co.

Possibly, judging alone from composition, from *o'a-bĭt*, yellow, + *ta'ka*, snow, + *m* + *pa*, water (or possibly in its other significance, top): hence "yellow snow water" or "yellow snow top."

O'gû-pa. North Spring, Skull Valley, Tooele Co.; also Barlow Creek in same place.

O'hû-pi-to-o-gû-pi. Boxelder Creek, Tooele Valley, Tooele Co.

O'mo-ti-o-gai-pi. Trout Creek, Tooele Co.

Om'bi. Pilot Peak Mountain, Tooele Co. (Deep Creek district).

O'na-bi. Nephi.

The word means simply salt, which was formerly obtained at this place.

On'gwitc-a-wünt. Red Butte Mountain, Tooele Co. (Deep Creek District).

O'o-gwa, O'o-ga. Ogden; Weber River; Weber Co.

From *o'pi,* wood, and *o'gwa,* river.

Pa'wĭn-tso-ga. Wood's Cross, Davis Co. "Springy or swampy ground."

Pa'ga-dĭt; Pa'ga-di-da-ma. Utah Lake, Utah Co. Also sometimes applied to Bear Lake.

Pa'ho-no-pi; Pa'o-no-pi. Skull Valley, Tooele Co.

The word means "water flat or hollow" and is applied to Skull Valley specifically because of the large playa occupying its center and covered during the wet season with a shallow sheet of water. The word is, however, also used in general for any such playa.

Pa'om-bo-dsĭp. Muskrat Springs, Skull Valley, Tooele Co. "Muskrat Spring."

Päñ'gwi-pa-dsûp. Spring Creek, Tooele Co. (Deep Creek region).

From *pan'gwitc,* fish, + *pa'dsup,* spring; "Fish springs."

Pa'tsĭn-ga-ri. Jimson's Spring Mountain, Tooele Co. (Deep Creek district).

Apparently meaning "Spring Mountain"; from *pa'tsi* up, spring, + *n,* possessive, + *ga-ri,* mountain.

Pa'so-ga. Lehi, Utah Co.

"Wet ground."

Päñ'kwi-o-gwa. American Fork; American Fork Canyon Creek, Utah Co.

"Fish Creek"; from *päñ'gwĭtc,* fish, + *o'gwa,* stream.

Pan'tsa-bĭtc-ûm-ba. Deep Spring, Skull Valley, Tooele Co.

Pan'tsa-bĭtc, a supposed water living creature, + *ûm,* possessive, + *pa,* water. The Gosiute believe certain creatures or "babies" can be seen in the spring at night and can be heard from a distance to cry. In the daytime they disappear in holes. See also *Tu'kai-pa-ri-tsi-pa.*

Pa'tsĭm-ba. Canyon Station, Tooele Co.

Seemingly "Spring water"; *pa'tsi-up,* spring, + *m,* possessive, + *pa,* water. See the next word.

Pa'tsĭ-wi-a. Same as preceding or nearly so, applying to same general region. "Spring way or road."

Pa'pa-dso-ki. Desert Mountains. Apparently "dry water or streams."

Pa'rĭ-bi-na (or *hna*). Antelope Island, Great Salt Lake.
"Elk place; elk breeding place."

Pa'rĭ-bĭn-o-gwût. Hickman Creek, Skull Valley, Tooele Co.
Pa'ri-bĭn, elk (ajective form), + *o'gwût,* stream; "Elk Creek."

Pa'o-hwû-pi. Hot Springs north of Ogden.

Pa'u-hna. Bird Island, Great Salt Lake.
"Seagull settlement or breeding place," this island being the nesting ground of vast numbers of seagulls whose nests thickly cover the ground during the breeding season.

Pa'wĭ-to-ga. Camel's Back Mountain, Tooele Co. (Deep Creek district).

Pi'a-bai-gwĭ-ci. Big Cottonwood Creek and Canyon, Salt Lake Co.
Pi'ûp, pi'a, big, + *bai'gwĭ-ci,* torrent, etc.

Pi'a-ga-ri. Black Mountain.
"Big Mountain."

Pi'a-pa. Great Salt Lake.
Pi'a, big, great, + *pa,* water. Also commonly termed *Ti'tsa-pa,* which see.

Pi'a-pa-rĭ-tsi-pa. Big Spring, Skull Valley, Tooele Co.
Pi'a, big, + *pa'rĭ-tsi,* spring, + *pa,* water.

Pi'a-roi-ya-bi. Deep Creek Mountains, Tooele Co.
Pi'a, big, + *toi'ya-bi, roi'ya-bi,* mountain.

Pi'o-gwût; pi'o-gwa. Jordan River.
"Big River."

Pi'a-pa-dsûp. Salt Springs, Tooele Co. (Deep Creek district).
"Big spring."

Pi'a-so-ho-gwa. Farmington Canyon creek; also the canyon.
Pi'a, big, + *so'o-pi*(*-o'ho-pi*), cottonwood, + *o'gwa,* creek.

Po'ho-ba. Grantsville, Tooele Co.
Po'ho-bi, cottonwood, + *pa,* water.

Po'ho-ba-dsûp. Antelope Creek, Skull Valley, Tooele Co.
Po'ho-bi, sage-brush, + *pa'dsûp,* spring, etc.

Po'ho-ri-ba-hna. Indian ranch or settlement in Deep Creek.

Po'ho-ri, sage-brush (adjective form), + *pa*, water, + *hna*, locative apposition.

Po'ko-ga-ri. Lakeside Mountains.

"Lizard Mountains" seems to be the meaning of this name: *po'ka-dji*, lizard, + *ga'ri*, mountain range.

Pu'hu-i. Beck's Hot Springs, Salt Lake Co.

Pu'hu-i-ba-ga-ra. Hot Spring Lake, Salt Lake Co.

Pu'hu-i, Beck's Hot Springs, + *ba'ga-ra*, lake.

Pu'i-toi-ya-bi, Pu'i-doi. Goose Valley Mountains.

Pu'i, duck, + *toi'ya-bi*, mountain.

Pu'i-tī-pa. Stockton, Tooele Co.

"Duck water."

Sai'ba. Flint Springs.

Saip, bulrush, + *pa*, water.

Sa'ma-ga-ri. Cedar Mountains.

Sa'ma + *gar'ri*, mountain range.

Si'a-dai-dī-ma. Little Cottonwood Creek, Salt Lake Co.

Si'o-pa. Ferguson Springs, Tooele Co.

"Willow water"; *si'o-pi*, willow, + *pa*, water.

Si'bû-pa. Camp Floyd.

Si'bû-pi, Bigelovia or rabbit-brush, + *pa*, water.

Si'hi-da-ro-wīn. Bountiful, Davis Co.

Sīñ'ga-wi-a. Birch Creek, Tooele Co. (Deep Creek district).

Sīñ'gû-pi, quaking-aspen, + *wi'a*, way, trail, etc.

Sīñ'go-gwa. Grouse Creek, Tooele Co.

"Quaking aspen creek."

Si'o-gwût; Si'o-gwa. Tooele, Tooele Co.

"Willow creek."

So'ho-gwa. City Creek and canyon, Salt Lake Co.

"Cottonwood Creek."

Sau'ga-toi-ya. See *Tsau'ga-toi-ya.*

So'ni-ba. St. Johns; Clover Creek.

So'nīp, grass, + *pa*, water; "grass water."

Co'kar-ni. Salt Lake City.

Cont, many, + *kar'ni*, house.

Ta'tsin-da-to-gop. Devil's Hole, Deep Creek district, Tooele Co.

Ta'tsi-yu. Grouse Creek Mountain.

"Setting star mountain"; *ta'tsi ump*, stars, + *ma-yu'*, to set, to go under.

Ti'bĭn-ha-ga-ri. Mountains South-east of Skull Valley; part of Oquirrhs.

"Pine-nut mountains or range."

Ti'go-a; Ti'ko-a. A small mountain standing by itself at north end of Skull Valley.

The word is probably from a verb meaning to separate, in reference to its central position by which it divides the valley (cf. *ti'go-ĭn*, plow).

Tĭm'pi. A place near the north end of mountains separating Tooele Valley and Skull Valley, a very rocky point. The name means simply "rock." It has been adopted as the name of a flag station on the Western Pacific Railroad which passes near the original *Tĭm'pi.*

Tĭm'pai yab. Springville, Utah Co.

Tĭm'pi, rock, + *toi'ya-bi*, mountain.

Tĭm'pĭn-o-gwût; Tim'pĭn-o-gwa. Provo; Provo River, Utah Co.

"Stony river"; *tĭm'pĭn*, stony (*tĭm'pi* + *n*), + *o'gwût*, river.

Tĭn'go-û-pi. Mill Creek Canyon, Salt Lake Co.

"Rock trap." The name is given in reference to the fact that the Gosiute formerly at favorable times surrounded game and drove them down a gorge to a precipice at one side of this canyon over which the frightened animals were caused to leap to their death.

Tĭn'toi-ya-bi. Mountains west of Great Salt Lake near Lakeside Mountains.

The name from its composition should mean "Rock mountains."

Toi'ba. Simpson's Springs. "Ascending Water."

To'a-na. Toana Springs, Tooele Co.

Toip, pipe (for smoking), + *hna*, locative apposition.

Tĭn'gan-o-nû-pi. Granite Creek.

"Rocky Gulch."

Ti'ni-pa. A spring near Beck's Hot Springs, Salt Lake Co., bearing no English name known to writer.

"Singing water."

Tĭ'tsai-ya-gi; Tĭ'tsi-ya-gai. Fish Springs.

Tĭ'tsa-pa. Great Salt Lake.

"Bad water"; *tĭ'tcĕn,* bad, bad tasting, etc., + *pa,* water.

Tĭ'a-bai-gwĭ-ci. Cherry Creek, Tooele Co. (Deep Creek district).

Tĭ'a, little, + *bai'gwĭ-ci,* stream, etc.

Tĭn'ai-gwo-bai(-o-gwa). Creek south of Butterfield Creek, Salt Lake Co.

Probably from *tĭn'ai-gwo-bi,* nettle, + *bai;* meaning to abound (+ *o'gwa,* stream, which is ordinarily omitted).

? To'ko-ga-ri. A mountain near Morgan.

To'sa-i-ba. Soda Springs, Utah Co.

To'sa, from *to'si-bĭt,* white, + *pa,* water.

to'no-ba-ga-rûp. General term for river bed or channel.

Tu'kai-ho-gwa. Kaysville, Davis Co.

Explained as meaning "big wind creek" in reference to the strong east winds that blow from the mountains at this place during part of the year.

Tu'kai-pa-rĭ-tsi-pa. Deep Spring, Skull Valley. Same as *Pan'tsa-bĭtc-ûm-ba,* which cf.

Tsa'po; Tsa'po-a. Emigration Canyon.

"Good road" is the meaning of the name, the trail, and later road, through the canyon across the Wahsatch Mountains being the best.

Tsau'ga-toi-ya. Dugway, Tooele Co.

From *tsau'ga,* dug out, etc., + *toi'ya-bi,* mountain.

Tĭn'tsai-hĭ-gi. Three adjacent mountains near Willow Springs.

Tu'tĭ-kwai-ba. Redding Springs, Tooele Co. (Deep Creek district).

The name seems to mean "Evening meal water."

Tsañ'ga-toi-ya. Bullionville.

Tsañ'ga + *toi'ya-bi,* mountain.

Tsi'a-ba. Clifton, Tooele Co.; Clifton Mountain.

"Dry Creek."

Tsi'a-ba-o-no-pi. Dry Canyon, east of Indian camp in Skull Valley.

"Dry Creek Hollow or Canyon," there being a stream of water from it only during the wet season and early spring.

tsi'ûm-pi; tsi'ûmp. General term for desert.

Wa'bi-koi. Rabbit Springs, Deep Creek district.

Wa'ga-tin-a-ru-a. A mountain a little west of Camel's Back Mountain.

Wa'ga-ri. Gold Hill, Deep Creek district.

Apparently "Double mountain."

Wa'hab-o-gwa. A small stream at Neff's ranch in Skull Valley.

Wa'ha-bi, divided, halved, half, + *o'gwa,* stream; "Divided or split creek," the name referring to the fact that the streamlet is formed by the water from two distinct springs which runs in two channels for some time before finally uniting into one.

Wa'ma-roi-ya-bi. Twin Peaks, Wahsatch Mountains.

"Double mountain."

Wan'dīñ-ga-nīp. Fish Spring Mountain. Also applied by some to Oasis.

Wa'nûp. Dalles Springs, Skull Valley.

Wa'pa-dsûp. Big Creek, Skull Valley.

Probably *wa'pi,* cedar, + *pa'dsi-ûp,* spring, etc.

Wi'am-ba-da-dsû-pa. Cedar Fort.

Wi'a-nûp. Shell Creek, Tooele Co.

Wo'tsa-na. Bingham, Salt Lake Co.

A recent name equivalent to "Mining Camp," Bingham being such.

Ya'hañ-go-a; Yañ'go-a. Stansbury Island, Great Salt Lake.

Yī'nīn-ga-ri. Porcupine Mountains.

"Porcupine range or mountains."

Personal Names.

Among the Gosiute many personal names are given in reference to some feature of the physical appearance. Thus, a boy with conspicuous ears that stand out from the head is named *Kûm'o-rûp,* meaning, in effect, "Rabbit ears" or "he with rabbit ears." Another young man who has a spinal curvature is called in full "*Ĭ'ca-gwaim-no-dsûp,* "Person whose back appears broken"; a girl with a considerable growth of hair on her upper lip goes under the name *Mû'tsûmp,* from *mo'tsu, muts,* meaning moustache; a boy who is tall is *Nan'nan-tci,* from *ma-na'hna,* to grow up, grow up high, and a tall woman is similarly called *Na'na-vi.*

Other names refer to peculiarity of manner or conduct or to some marked personal habit. Thus a man who for many years inveterately used a peculiar pipe in smoking, even putting his cigarettes into the bowl and smoking them through it, was named *Toip*, "Pipe"; a woman who weeps much because all her near relatives are dead is known as *Ya'ki-kĭn*, from *ma-ya'ga*, *ma-ya'gi-kĭn*, to weep or cry; a woman of happy disposition who smiles much is *Pai'yă-nuk*, "Rippling or Laughing Water"; and another of opposite disposition is named *Tu'o-bai*, apparently from the root seen in *tu'o-bĭt*, dark, black, and in *tu'o-bûk*, angry, with the addition of *bai*, abounding in; and *Tai'bo-hûm* is one name of a boy who is noticed especially and admired by white people (*tai'bo*, white person).

Some names are taken from places and materials. Examples are *An'tsi*, meaning a flat without grass, and *Ai'bĭm-pa*, a stream and place in Deep Creek, men's names; and *Pa'ri-gwĭ-tsûp*, mud, and *Gwa'na-se*, sand, women's names. Names of various other objects are frequently applied to persons. Such are *Po'go-nûp*, currant; *Kun*, fire; *Mu'nai*, from *Mu*, moon; and *Ta'bi*, sun, the latter the name of the last chief of the tribe. The same name was a common one for chiefs of other tribes as well and seems to have been restricted to such persons. An interesting case that came to the writer's attention was in the naming of twin children, one a boy and the other a girl. The boy was called *Sa'gûp*, one of the willows, and the girl *Pi'o-ra*, sweet-pea, one form of which lives among and climbs upon the willows, the two names being selected because of this association.

Animal names are borne both by men and by women. These names are frequently chosen without any obvious association or particular reason; but in other cases they are given because of a personal trait or feature's suggesting the animal concerned, as when an active, romping girl was named *Mûts'ĕm-bi-a*, mountain sheep. Other examples of names of this type are *Wu'dĭ-tci*, black bear, a man; *Hoi*, chipmonk, a boy, and *Pĭn'ji-rû*, a bird, applied to a woman.

Finally, a considerable number of names are taken from other Indian tongues and, at present, also from English. Thus from the

Kanosh Ute is *Kĭ'ûn-gwa*, a woman's name; from Paiute, *Ai'pûb*, a boy's name which means simply "boy"; and from English, *Wĭ'ni*, Winnie, and *Nĭ'na*, Nina, *Ta'di-ĕn*, for Italian, given to a boy thought to resemble an Italian, and *Pĭ'gi-stun*, one of two names borne by a woman, this one having originally been coined in jocular way from the English "big stone" in reference to her large size.[4]

As might be expected from the manner in which personal names commonly originate, the same person frequently receives several in the course of his life. The name borne in childhood perhaps in most cases is changed in later life; while the name of an adult may be suspended or used interchangeably with another given in consequence of some newly acquired characteristic or of some event of importance in his life. Thus the man mentioned previously as bearing the name Toip has also been known as *Nam'pa-cu-a*, "He who drags his foot" or "Foot dragger," since through an accident he lost one foot and has had to wear a wooden substitute which leads him to shuffle in walking. Various other cases are noted in the list of names below.

The following list includes chiefly the names of persons living, or recently living, in the Skull Valley branch, though a number of those of members of the Deep Creek colony are included.

Ai'ba-pa. A man. The name is sometimes heard in the etymologically more correct form *Ai'bĭm-pa* and also as *Ai'pa-bi*, the transfer of vowels or entire syllables in this way being a common phenomenon in Gosiute. The name means "Clay water" and

[4] In similar spirit originated the name *Pĭ'gĭn-gwa-ci*, by which a white woman, who as a girl played much with the Indian children and learned their language simultaneously with her own, has for thirty-five years been known to the Gosiute. Her given name was Tillie, and that of her younger sister Lillie; but as the Gosiute have no l sound in their language, they find it difficult to pronounce English words containing it, especially when initial, and usually replace it by t or d (cf. *Ta'di-ĕn* given above); and hence, they pronounced both these names alike. To distinguish one from the other Tillie, the elder, was in speaking to white people mentioned as "big (pig) Till" and the younger as "tiddy (little) Till." Big Till or, as commonly sounded, Pig Till, soon suggested Pig Tail and was then promptly translated into the Gosiute as *Pĭ'gĭn-gwa-ci*, from pig, + *n*, possessive, + *gwa'ci*, tail.

is the Gosiute name of a stream in the Deep Creek Valley and of the adjacent region.

Ai'go-re-a. An old man recently deceased. He was also known as *Mu'nai.*

Ai'pûb. A boy. The name is from the Piute, in which language it means "boy."

Ai'ci-wap. An old man.

Añ'gĭp. A woman.

Am'bo. A woman.

Añ'gots. A man, known to the whites as Charley. The name is possibly originally from the word meaning spruce, *añ'go-bi,* plus the ending *ts, tsi.*

Äñ'ka-bi-pi-dûp. A woman. The name is approximately equivalent to the English word "ghost."

Äñ'ka-rau-ga, Häñ'ka-rau-ga. A woman.

An'tsi. A boy. The name was explained as meaning a barren flat, one on which no grass grows.

A'pam-pi. One name of the last chief of the tribe who was also known under the common chieftain name *Ta'bi.* The name means literally "horn head," and refers to the headdress formerly worn by the chief.

A'rĭm-pi. A man. The name is applied to a particular kind of earth or clay and also to the Dugway Mountains.

Au'wi-a. A woman, wife of *Ĭn'gĭ-tsi.*

Bi'bo-rĭn. A woman.

Bo'ni. A boy.

Dai'gi. A boy.

Dsa'kûp. A girl. The name means simply "broken."

Gwa'na-se, Gwa'na-si. A woman. The name means "sand."

Haink. A girl.

Ham'bu-i, Am'bu-i. An old woman. The name means filmy or blind eye (*bu'i,* eye).

Hoi. A boy. The word means "chipmonk."

Ĭñ'gĭ-tsi. A man, recently deceased, known to the whites as Dick.

Ĭ'ca-gwaim-no-dsûp. A boy. The name means "back falsely broken"

or "apparently broken" (*I'ca*, false, not truly, *gwai'ûmp*, back). Refers to a curvature of the boy's spine.

Ka'sĭ-tsi. A girl.

Ka'wi-yai-ya. A boy, also known as *Po'gûm-pi.* The name refers to his large ears.

Ki'ûn-gwa. A woman. Name from the Kanosh Ute.

Kûm'o-rûp. A boy. "Rabbit ears" (*kûm*, rabbit, *ro*, root, meaning to extend out, etc., *ûp*, nominal ending).

Kun. A boy. The name means "fire."

Ku'sa-yu-main. A girl.

Ku'si-a-mû-tci. A girl.

Man'tsi-rĭtc. A woman. The name is from the verb meaning to hold the hands in the supine position plus the ending *ts* (*tc, tci*), and refers to the woman's habit of putting her hands in this position.

Ma'ro-pai. A boy. "Fighter," from *ma-ro'pain, ma-ro'pain-do*, to fight (with fists).

Mĭ'tos. A girl.

Mo'rants. A woman.

Mo'ro-wĭntc. A woman. The name refers to habit of frequently turning up her nose (*mo'bi*, nose, + *ma-ro-wĭn*, to pull or draw, draw up).

Mu'i-dsa. A girl.

Mu'nai. A man, also bearing the name *Ai'go-re-a.* Now deceased. From *mu*, moon.

Muts'ĕm-bi-a. A girl, now deceased. "Mountain sheep."

Mu'tsûmp. A girl. From *mo'tso, muts*, moustache, given in reference to growth of hair on upper lip.

Nam'pa-cu-a, Nam'pi-cu-a. A man also known as *Toip.* The name is from *nam'pa*, foot, plus the verb *pi'cu-ûn*, to slide or drag, shuffle, and is applied for the reason previously explained. The man is known to the ranchers as Dave Kimball, having as a child been adopted into a white family of that name, his immediate relatives appearing to have been killed in an early battle with whites. He later took up life with the Gosiute, of which tribe he is not a native.

Nan'nan-tci. A boy. From *ma-na'hna,* to grow up, grow up tall, plus the ending *tci.*

Na'na-vi. A woman, now deceased. Apparently from same verb as the preceding.

Na'tcu. A girl.

Nĕ'ji-ka. A girl. The name was said to refer to the way in which at one time she had had her hair cut.

Nĭ'na. A girl. From the English.

No'wi-ûp. A woman. *Ma-no'wi-a,* to carry or move away, move camp, plus *ûp.* "Camp mover."

Oi'tcu, Oi'tco, Hoi'tcu. A boy. The word means "bird" in the general sense.

Pai'yăn-uk. A woman. "Laughing Water" (*Pa,* water, + *ma-ya'ni-kĭn,* to laugh).

Păn'du-gan. A man. Probably from *pan,* water (adjective form), and *Tu'gan,* which see further.

Pantc. A man, also known as *Pĭ'dji-bu-i.* Name probably the English paunch.

Pa'ri-gwĭ-tsûp. A woman. "Mud" is the meaning of the name.

Pa'so-go. Name by which *Pa'ri-gwĭ-tsûp* was known when a girl. The name means wet or swampy ground.

Pa'wi-noi-tsi. A man spoken of in tradition as having a very long time ago built a vessel and navigated the Great Salt Lake (*Pa,* water, + *wi'a-no,* to travel or ride, + *tsi*).

Pĭ'a-re-gwa-ni. Gosiute name for *Wa-ce-ki,* the Shoshoni chief, It means "great talker."

Pĭ'a-waip. A woman, also known as *Pĭ'gi-stun* or *Stun* for short. The name means simply "big woman" (*pĭ'a,* big, + *waip,* woman).

Pĭ'gĭñ-gwa-ci. Name of a white woman formerly much associated with members of the tribe. It means "pig tail" (*pĭgĭn,* pig, in adjective form, + *gwa'ci,* tail). The manner of origin of this name has been explained above.

Pĭ'dji-bo-ûnts. A man, often also called *Pantc.*

Pĭ'kĭn. A girl.

Pi'kĭp. A woman.

Pĭ'gi-stun. A woman, formerly known exclusively as *Pi'a-waip,* but now called more frequently by the present name or its shortened form, *Stun.* It was coined from the English "big stone."

Pĭ'ku-rĭnk. A man.

Pĭñ'ji-rû. A woman. Name of a bird.

Pĭ'dji-bu-i (*Bĭ'dji-bu-i*). A girl. The name refers to her having precociously developed mammæ (*bi'dji*).

Pi'o-ra, a girl. "Sweet Pea" (Hedysarum, etc.).

Po'go-nûp. A boy. "Black currant." The name also occurs in the form *Po'gûm-pi.*

Pcäñk'. A boy.

Pu'i-dja. A man. The name appears to be from the English "pudgy" applied to him by whites and adopted.

Sa'gûp, a boy. Name of one of the willows.

Si'ĭ-tci. A boy.

Si'u-wa. A woman.

Cĭl. A man.

Ta'bi. Last chief of Gosiute, also known as *A'pam-pi.* "Sun."

Ta'di-ĕn. A boy. From "Italian," the boy having been thought to resemble one of that nationality. The l of Italian is replaced by *d*(*t*), as usual.

Tai'bo-hûm. A boy, so called because a favorite with white people (*tai'bo*).

Toip. A man, also known as *Nam'pa-cu-a.* The name means pipe and the manner of its origin has been explained previously.

To'mûc. A man, commonly known as *Wu'dĭ-tci.* From English Thomas, probably.

Tu'gan. A man. From *tu'ga-nĭñ,* night, darkness.

Tu'o-ba. A woman. "Dark Water."

Tu'wats. A girl.

Tsai'yap. A woman.

Wa-da'tsi, Wa'da-tsi. A man. "Bitter" plus nominal ending *tsi.*

Wa'ci-doi-û-pa. A name for *Wa'ce-ki.* See also *Pi'e-re-gwa-ni.*

Wac. A man.

Wĕs. A man.

Wi'a-so. A woman.

Wi'ni. A girl. English Winnie.

Wu'da-tci, Wu'dä-tca. A man. The vowels may be interchanged, as frequent, and the name be heard as *Wu'dī-tca.* It means "black bear."

Ya'go-tsŭp. A woman.

Ya'ki-kīn. A woman. So called because of her much weeping, all her relatives being dead.

PLATINUM IN NORTH CAROLINA.

BY PAUL R. HEYL.

(*Read February 7, 1913.*)

North Carolina, on account of the variety of different minerals it affords, may well be classed with Freiburg, Saxony, and Franklin, N. J. More than one hundred and eighty different minerals occur there, and in some cases minerals otherwise rare occur there in commercial quantities.

The gold mines of North Carolina have been known for a century, and it would be but natural to expect small quantities of platinum to be found in such localities. The first announcement to this effect was published by Shepard in 1847.[1] It appears from his report that a nugget of platinum weighing 2.5 grains was found among the gold washings in a rocker at Mr. Erwin's mine in Rutherford county. The miner who picked it out supposed it to be silver, and other miners in the vicinity claimed to have seen similar lumps occasionally. It would seem, however, that such occurrences must be very exceptional, as Hidden,[2] in 1881, failed to find any platinum in five localities, and Venable in 1892,[3] after a careful examination of gold washings from several places and a failure to find any platinum therein, was inclined to distrust Shepard's report.

In 1894,[4] however, Hidden discovered sperrylite, the native arsenide of platinum, in panning gravel from a creek in Macon county, and traced it to its source in rock on the top of a mountain.

The present communication deals with the occurrence of platinum in a different part of the state, and is believed to be the first published notice of the subject. The interest centers around the little village of Ruffin, in Rockingham county, about fifteen miles south of Danville, Virginia. The country hereabouts is devoted mainly to farming, tobacco being the chief crop. Apart from a

[1] *American Journal of Science*, series 2, Vol. 4, p. 280, 1847.
[2] *Ibid.*, series 3, Vol. 22, 1881, p. 25.
[3] *Ibid.*, series 3, Vol. 43, 1892, p. 540.
[4] Kemp's "Report on Platinum," *Bull. U. S. Geol. Survey*, No. 193.

granite quarry a few miles south of the village no form of mining is practised in the neighborhood, although some fifty miles farther south, near Cedar Falls, gold is extracted from a rock deposit in which it occurs rather irregularly.

The beginning of the platinum story goes back some fifteen or sixteen years. At that time, according to neighborhood tradition, the son of a Mr. Harralson, a landowner in the vicinity, picked up in the creek a stone which attracted him by the yellow crystals scattered through it. Supposing it to be gold, he showed it to his father, who sent some of the rock for examination to a Mr. Wilson, at that time chemist for a phosphate concern in Baltimore. Mr. Wilson saw at a glance that the supposed gold was pyrite, but thought it worth while to see if the pyrite was auriferous, and directed his assistant, a Mr. Walsh, to make some assays. Mr. Walsh found no gold, but encountered something else which puzzled him for a while, until he finally obtained a reaction for platinum.

The quantities of platinum shown by this sample of rock were surprising. Four assays in Mr. Wilson's laboratory gave the following figures in ounces per ton: 4.76, 2.40, 2.85, 3.60. More rock was sent up at Mr. Wilson's request, and four more assays were made, all of which were blank. Greatly incensed at what he supposed a trick, Mr. Wilson visited the ground and nearly came to blows with Mr. Harralson. Finally convinced of the latter's sincerity, Mr. Wilson proceeded to investigate the matter on a large scale. He turned the creek out of its bed and put down a charge of dynamite. Samples of this rock again showing platinum, a car load was sent to the Mecklenburg Iron Works, in the same state, and there ground and washed on a Wilfley table. The following results were obtained:

Concentrates 30 to 1. Ounces Per Ton in the Concrete.
97.2
18.0
61.2
42.0
10.2
24.6
25.2
42.0

Mr. Wilson also put down a hole in the ground by the creek side and took some rock out which yielded nothing but blanks. He seems then to have become discouraged, and soon afterwards died, being over 80 years of age. His assistant went to Mexico, where all trace of him was lost.

I have given the story thus far somewhat in detail, as it illustrates so well the characteristic features of the deposit, and the experience of every one who has worked with it. The details were given me personally by Mr. Harralson. As this occurred about the time of the gold discoveries in Alaska the particular spot where the platinum was found was called the Klondike, which name it bears to this day.

A few years after this the matter came to the attention of Dr. C. D. W. Colby, then of Dillsboro, Jackson county, N. C., now of Asheville, who has been since that time its most earnest and persistent advocate. Much credit is due him in this matter. Starting, as he himself states, with the very elementary knowledge of platinum possessed by the average practicing physician, and with the still more elementary facilities at his disposal in a mountain village of western North Carolina, he was able to satisfy himself that the rock contained platinum, and in what he believed to be paying quantities.

Following are the results of certain assays made for Dr. Colby by a Mr. Jenkins, chemist for a copper company operating in the western part of North Carolina.

3.27	0.65	1.31	0.65
1.31	1.31	trace	0.71
3.73	3.85	0.16	trace
3.60	3.76	0.24	
3.92	0.71	0.32	

These assays were all made by the wet method, and in addition to these figures many blanks were obtained. Dr. Colby also obtained the following figures, together with a number of blanks, from well-known professional assayers:

F. F. Hunt, New York	2.6
Trubeck	3.1
Ledoux and Co.	3.07
G. C. Childress, Knoxville	1.0

Dr. Colby then began a most discouraging nine-year campaign of promotion, bringing the matter to the attention of practically every large platinum-working concern in this country, and last of all to the concern with which I am connected.

It was the same story everywhere. His tale was listened to with more or less interest, the samples were turned over to the company's chemist, who invariably reported "no platinum." Then a letter, not always too polite, closed the negotiations in that direction.

Dr. Colby, having several times been able to correct professional assayers to whom the examination of the rock had been intrusted as to the proper handling of a silver bead containing platinum, became convinced that the trouble lay with the chemists; that the platinum existed in the rock in some new form, which required a special method of analysis to detect it.

In the course of the campaign the matter was brought to the attention of the United States Geological Survey, and Dr. Day and Mr. Sterrett visited the ground. A car load of rock was taken out and tested on one of the concentrating tables which had proved very successful on the black sands of the Pacific coast. The examination of the concentrates showed no platinum. Dr. Colby had some experiments made with dry concentrators, which he says gave fairly good results. No figures on these results were furnished us.

The matter came to our attention early in the year 1911. The first thing to be done in the matter was to write to the Geological Survey.

The reply of the Survey stated that nothing had been published on the subject; that the rocks in the vicinity were hornblende schist and sericite quartz schist, which might represent metamorphosed phases of volcanic rock such as andesite and rhyolite; that it was claimed that the sulphides in the hornblende schist carried platinum in some form difficult to extract; and that the Survey had not determined this point.

With this curious history of the situation laid fully before us we were inclined to place considerable confidence in Dr. Colby's hypothesis of a new form of occurrence of platinum. Bearing in mind that the properties of compounds in the native state are often very dif-

ferent from their properties when artificially produced (*e. g.*, the insolubility in acids of certain native oxides of iron, and the comparative insolubility in aqua regia of sperrylite), we thought it not unreasonable that we might have to deal with a new compound of platinum of peculiar properties, and in the examination of the rock we were careful to follow Dr. Colby's directions literally, however useless it might seem.

The first sample submitted by Dr. Colby weighed about five pounds. One third of it was retained for examination in our laboratory, and the remainder, in lump form, was sent to Dr. Harry F. Keller, of Philadelphia, who ground it, divided it into two portions, retained one himself, and sent the other to Mr. Whitfield of the laboratory of Booth, Garrett and Blair. The portion analyzed at our laboratory was decomposed by aqua regia, according to Dr. Colby's directions, and yielded the surprising figure of eight ounces of platinum and two ounces of iridium to the ton. Dr. Keller and Mr. Whitfield decomposed the rock by hydrofluoric acid and Dr. Keller found six tenths of an ounce of platinum to the ton, while Mr. Whitfield found nothing.

Mr. Eldred, of our company, then visited the ground, took his own samples and brought them north in his hand satchel. Two assays on these samples, by the fire method according to Dr. Colby's directions, gave 0.8 and 1.1 ounces per ton platinum.

The services of an experienced mining engineer, Mr. James W. Neill, of Pasadena, Cal., were then called into requisition. Mr. Neill visited the ground with Mr. Eldred, and took samples from eight localities. The assays of these, by the fire method, gave the following figures:

0.2 0.3 0.2 trace 1.25 0.4

and two blanks.

I will not take the time to go over in detail all the assays that were made on the property. Suffice it to say that over fifty assays were made in our laboratory, a few of which were blanks, a larger number gave perceptible traces, and a smaller number ran anywhere from half an ounce to one ounce per ton. Nothing approaching the figure given by the first sample was ever found again.

At an early stage of the assaying work it was recognized that to carry out such work in the laboratory of an industrial works devoted to the working and refining of platinum on a large scale was a matter of some delicacy. The obvious way to guard against infection was to run blanks, and this was done with perfect success for eight months. At the end of that time the furnace in which the assays were made began to show signs of infection from the fine platinum dust that might be detected almost anywhere in the works, and the blank assays began to give minute traces of platinum. A new furnace was then installed in another room, and satisfactory blanks were again obtained. It was not considered prudent to do much in the way of sending out samples to other laboratories for check analyses, but such check assays were made in our own laboratory by Dr. Harry F. Keller, of Philadelphia, and the results agreed quite well with our own figures. As an illustration of the care that was taken to avoid false results, the air supply of the furnace was examined. The furnace was fired by gas mixed with air supplied from a blower in a distant room. This blower supplied air to all parts of the establishment, and its intake was not above suspicion. A glass tube filled with cotton wool was fastened to one of the air cocks and the air allowed to blow through it for two weeks. The cotton was then burned and the ash examined for platinum. None was detected.

The examination of the ground was carried out by our mining engineer, Mr. James W. Neill, with great thoroughness. Samples were taken over an area of six or seven square miles in the immediate vicinity of the Klondike, and the peculiar rock of the region was traced fifteen miles north, to Danville, Virginia, and fifty miles south, to a point near Cedar Falls, N. C., and traces of platinum were occasionally detected in it. The work lasted a year, and was completed by an examination of the watershed of the region for placers. This latter piece of work was done by Mr. John A. Ritter, and extended far and wide, in the case of one river to a point two hundred miles from Ruffin. In this examination traces of platinum were found in the sands of the James river two miles west of Richmond; in the Dan river, where it is joined by Hogan's creek, which drains the Ruffin region; in the Dan river at Danville, Va.; in the

Roanoke river at Weldon, N. C.; and in the creek bed on the property at Ruffin. The richest sample (and the only one yielding enough platinum to weigh) was from the mouth of Hogan's creek. It contained about forty-five cents' worth of Pt per ton of gravel. Another sample taken only a few yards away was blank. This was the uniform experience wherever Pt was found, pointing to the occurrence of the metal in sparsely scattered single particles. In all other cases where Pt was found it was merely as an iodide reaction.

Traces of gold were found at the mouth of Hogan's creek and in the Dan river near Clarksville, Va.

But I take it it is of less interest to the present gathering to learn that the platinum deposit of North Carolina is commercially unimportant than to learn something about the nature of the rock that carries the Pt, and the form in which the metal occurs.

As you see by the samples the rock is evidently sedimentary in its origin. It has a density of 3.03. On roasting it becomes so friable that it may readily be reduced to its grains by the fingers. An analysis of the principal constituents of the rock, made at the Massachusetts Institute of Technology, gave the following figures:

SiO_2	50.01
CaO	9.02
MgO	4.83
Al_2O_3	15.21
Fe	9.66
TiO_2	2.45

The rock also contains the alkalies and varying amounts of sulphur. It is noteworthy that it appears to contain no chromium. The sulphur is present as sulphides of iron, in two forms, soluble and insoluble in hydrochloric acid, probably the ordinary pyrrhotite and pyrite. It was Dr. Colby's idea that the sulphides carried the platinum. Our experience negatives that. The samples richest in Pt were often poor in sulphides. Occasionally large crystals of sulphides would be found, and an assay of the hand-picked sulphides showed no platinum.

In order to determine, if possible, the form in which the platinum occurred in the rock about 150 assay tons of rock were coarsely

crushed and then ground to fine powder in rolls, with the idea of finely dividing the rock without reducing the size of the metallic particles, if any such were present. The ground mixture assayed 0.4 ounces per ton Pt, which would mean 60 milligrammes of metal in the lot. Concentration was effected by very gentle washing in the following manner: the sand was placed in a large jar, and a small stream of water introduced by a tube reaching to the bottom of the jar, and the water allowed to overflow until it ran perfectly clear. The residue, which amounted to about one third of the original amount, was dried and put through the rolls again, afterwards being washed in the same manner as before. After several repetitions of this process there remained a few grams of material, which was pulverized by hand in an agate mortar filled with water, a little at a time. The very fine material thus resulting was panned off from time to time and there remained finally a surprisingly large amount of flattened metallic particles. On digestion with hydrochloric acid the greater part of these dissolved with the familiar odor which showed them to be particles of steel derived from the grinding machinery. There remained 13.8 mg. of bright metallic particles. These were not attacked by dilute nitric acid. On heating to redness on the lid of a porcelain crucible many of the particles preserved their luster unchanged, and some of them turned a steel blue without loss of luster. A few particles showed the change of color over a part of their surface, suggesting palladium. (Samples.)

The quantity of material was rather small for an analysis, but the attempt was made. The particles were fused with zinc for an hour and the button dissolved in hydrochloric acid. The fine black residue was treated with aqua regia diluted with four volumes of water for a long time, and there remained a small black residue which was probably iridium. It weighed 0.4 mg., and was unaltered in appearance by ignition. The solution was evaporated to dryness and taken up with 60 per cent. alcohol and solid NH_4Cl. A small brick-red precipitate remained. On ignition the mixed Pt and Ir sponge weighed 7.7 mg. The alcoholic filtrate was yellowish, and gave a reaction for iron. This is significant in connection with the fact that the particles had withstood both hydrochloric and dilute

nitric acids. On warming the alcoholic filtrate it turned a deep brown color, again suggesting palladium. From the filtrate 2.7 mg. Fe_2O_3 were obtained by precipitation with ammonia.

The 7.7 mg. of Pt-Ir sponge was treated with dilute aqua regia until a constant residue was obtained, which weighed 1.8 mg. Adding this to the 0.4 mg. previously obtained, we have about 16 per cent. Ir. The Pt figures about 40 per cent. and the Fe 15 per cent., leaving 29 per cent. unaccounted for. No further evidence of Pd could be obtained from the very small amount of material.

The total recovery of acid-resisting metallic particles by this method was only about 25 per cent. of the assay value of Pt, and undoubtedly comprised only the largest particles. The term largest is to be understood in a relative sense only, as none of the particles could have weighed as much as 0.1 mg.

There seems to be no doubt that the platinum exists in the rock in the form of the usual alloy or mixture of the different platinum metals and iron, with probably a greater proportion of iridium than is usual in the Russian variety. It is worthy of note that as far as is shown by the various published analyses of platinum from American sources these ores have a greater iridium content than the ores from Siberia.

As an experiment on a larger scale, half a ton of rock from a locality about two miles distant from the Klondike was smelted in the experimental blast furnace at the Massachusetts Institute of Technology, and yielded 11 mg. of platinum. A sample of this rock had given an assay value of 0.4 ounces per ton, accompanied by a satisfactory blank. A second assay had yielded nothing. It was customary to make assays on 4 A. T. lots of ore.

All the foregoing facts are consistent with the hypothesis that the platinum exists in the rock in sparsely scattered granules, so few in number that by no amount of rolling and mixing can we bring the sample into such a state that there will be at least one such granule in each assay ton of the ore.

As a matter of interest, during the progress of the assaying work on the North Carolina rock, we were led to examine samples of rock from a great many localities for platinum. The curious fact

was discovered that it was almost impossible to obtain a blank when the rock was largely ferruginous, while on rocks composed mainly of quartz there was no difficulty in this respect. In no case was anything more than the extremely delicate iodide reaction obtained. In applying this test it is important to note that it is interfered with by the presence of iron, nitric acid, and alcohol. The latter substance is likely to be the most frequent cause of failure to obtain the reaction. In certain ferruginous rocks, when the point was reached where the platinum, if present, should remain insoluble on the watch glass after taking up the sal-ammoniac with 60 per cent. alcohol, there was often an almost microscopic trace of a white residue. Performing the filtration by faith, and washing with 95 per cent. alcohol, also by faith, the critical point of the procedure was reached. If the supposed precipitate was now dissolved off the filter by hot water, no iodide reaction could be obtained; but if the filter was first dried until all odor of alcohol had disappeared, an iodide reaction could often be obtained. In this way reactions were obtained from certain building stones from Lower Merion township, Montgomery county, Pa., and from a trap dyke in the neighborhood of our laboratory in Westchester county, N. Y. The sands of the Bronx river, a small stream in our vicinity, gave no reaction when unconcentrated, but when concentrated by hand panning a reaction could be obtained. Bearing in mind the relation of platinum to the iron group, and the fact that iron always accompanies platinum, it is not so surprising that platinum should occur in small traces with iron wherever the latter is found.

We also examined the rocks near Sassamansville, Berks county, Pa., which are mentioned in Kemp's report as giving irregular indications of Pt, and found iodide traces in several samples. To judge by the depth of color, these samples were not as rich as certain of the Lower Merion building stones.

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THE FORMATION OF COAL BEDS.[1]

IV.

By JOHN J. STEVENSON.

(Read April 18, 1913.)

CONTENTS.

The Coal Beds.

Coal beds are intercalated between rocks of different composition and apparently of different origin. The deposit may cover only a few square yards or thousands of square miles; its changes in thickness may be abrupt or may be so gradual as to be unimportant in a considerable district; the structure may be variable or it may be

[1] Part I. appeared in these Proceedings, Vol. L., pp. 1–116; Part II., in the same volume, pp. 519–643; Part III., in Vol. LI., pp. 423–553.

so constant as to characterize the bed in great areas; the composition of the several divisions may be similar or in great contrast; the relations of a coal deposit to the associated rocks may be so intimate as to be interdependent or the association have all the appearance of accident. One must study these conditions and their interrelations.

Explanation of Terms.

Classification of the fossil fuels is foreign to the subject of this work, belonging rather to a study of the origin of coal; here, certain familiar terms are used in a broad sense and the whole series from peat to anthracite is taken to be continuous—at least, from the chemist's point of view. The chemical relations existing between members of the series have been expressed in many ways; but this table from Muck[2] answers the present purpose:

	C	H	O	N
Woody fiber	50	6	43	1
Peat	59	6	33	2
Brown coal	69	5.5	25	0.8
Stone coal	82	5	13	0.8
Anthracite	95	2.5	2.5	Trace

The mineral content is ignored in this comparison. The table like all others, is merely a generalization and the boundaries between groups are arbitrary. The passage from one to another is gradual and in each the variations are extreme.

Peat is the accumulation of vegetable matter decomposed in presence of a constant supply of water and protected from access of oxygen. It occurs in areas of greater or less extent on the present surface or in Quaternary deposits. Plant structure is readily recognized in the newer portions but, in the thoroughly matured peat, it can be detected only by aid of the microscope. Under prolonged pressure, peat may assume the appearance of typical brown coal. Lesquereux,[3] cited on an earlier page, saw peat exposed midway in the valley of the Locle, where it is dug. At a little way toward the hills, it is covered with 4 feet of marl and is much changed in ap-

[2] F. Muck, "Die Chemie der Steinkohle," 2te Aufl., Leipzig, 1891, p. 2.

[3] L. Lesquereux, "Quelques recherches sur les marais tourbeux," Neuchatel, 1845, p. 95.

pearance, though still distinctly peat; but on the border of the valley, where the marl is thick, the peat has been compressed to 3 inches and has become a brown coal, hard, fragile and with brilliant fracture. G. M. Dawson[4] found on Belly river, a bed of interglacial peat, hardened by pressure so as to have the appearance of lignite.

Brown coal or lignite exhibits a more advanced stage of chemical change and is the ordinary type in Mesozoic and Tertiary deposits, though it is not wanting in the Quaternary, for the beds at Dürnten and elsewhere in Switzerland as well as at localities in Bavaria must be accepted in great part as brown coal. At times, vegetable structure is thoroughly well preserved, especially where stems of trees are present; at other times, the whole mass is amorphous, while at still others, both forms occur in a single layer, recalling the condition so often seen in mature peat. Lamination is reported from many localities. The color varies from dingy brown to coal black and the luster from earthy to briliant, but the streak is brown. Brown coal is not unknown in Palæozoic deposits. The great beds of the Decazeville basin, France, two of which have a maximum thickness of more than 100 feet, show all external characteristics of stone coal, but they contain more oxygen and nitrogen than is found in ordinary brown coal and more than twice as much as is present in air-dried stone coal.[5] The brown coal from Tula in Russia has been studied by many palæobotanists. In spite of its ancient origin, it approaches very closely to lignites in appearance and composition. Nikitin[6] states that there are several beds, more or less important, in the lowest part of the Carboniferous and that boghead is associated with the coal. In this connection, it may be well to recall the remarkable observation by David,[7] which appears to have been overlooked. He discovered in soft fine clay of Carboniferous age thickly matted

[4] Cited by J. W. Dawson, "Canadian Ice Age," 1892, p. 724.

[5] N. Saint-Julien, cited by J. J. Stevenson, "The Coal Basin of Decazeville, France," *Ann. N. Y. Acad. Sci.*, Vol. XX., 1910, p. 272.

[6] S. Nikitin, "De Moskou à Koursk," Guide des excurs. VII., Cong. Géol. Int., 1897, XIV., p. 5.

[7] T. W. E. David, Ann. Rep. Dept. of Mines, New South Wales, 1890, p. 229.

layers of undecomposed *Glossopteris* leaves, not brittle but retaining their original substance; soaked in glycerine and water, they can be unrolled and laid flat. A large number of the specimens were mounted and placed on view in the museum of the Department of Mines at Sydney.

Stone coal marks a still greater advance in chemical change. With rare exceptions, it is laminated, black or grayish black, more or less lustrous and with a black streak. In nearly all stone coals, there are alternations of bright and dull laminæ, the Glanz- and the Mattkohle of von Gümbel, which may be extremely thin or several inches thick. Usually, there is little macroscopic evidence of plant structure, aside from the mineral charcoal, mother of coal, fusain, Faserkohle of authors, which resembles charred tissue. This is the ordinary coal of the Carboniferous and it is present in many localities of later Cretaceous age. The difficulty encountered in the effort to define a limit between brown and stone coal is increasingly great, as the determination is of commercial importance in the western United States, especially in areas where both types occur in the Mesozoic. Stone coals have been divided commercially into bituminous and semi-bituminous on the basis of volatile content, but this does not suffice for distinction from the brown coals. The latter have been termed hydrous coals because they contain much water, apparently combined, and break up rapidly on exposure to the air. But many so-called anhydrous coals break up with equal readiness on exposure to dry air. It is quite certain that typical Carboniferous coals have, for the most part, a definite prismatic cleavage and that many brown coals lack that feature, while some have it. Many methods of distinguishing the types have been suggested, but none is satisfactory; the exceptions are too numerous to prove the rule. No hard and fast line between brown and stone coals exists except in generalized tables; but, as a rule, the older coals are more advanced in chemical change than those in later deposits.

Anthracite resembles stone coal in structure and often in appearance, but it is more brittle and more brilliant. The volatile content is small, often approaching a trace. Like the stone coal, it often contains much mineral charcoal, thus showing relationship to the

other members of the series, since mineral charcoal is a common constituent of the brown coals as well as of peat.

The series is continuous. By slow destructive distillation under pressure all can be converted into anthracite. The coal at Decazeville is much given to spontaneous combustion and the operators suffer great loss not only by destruction of the coal but also by conversion of much into a dense brilliant anthracite. The change of brown coal into anthracite by eruptive rocks is a common phenomenon in both Europe and America, so common that anthracite is thought by the great majority of students to be a metamorphic coal.

Beside the ordinary coals, which have so many features in common, there are some which might be termed aberrant forms, the cannels, bogheads, kerosene shale; these, which have been termed sapropelic coals, are minutely laminated, brownish black and have a brownish streak. Ordinarily, they are rich in volatile constituents, which give much more brilliant flame than those from bituminous coal. In mode of occurrence and in some structural features they resemble the organic muds or sapropelites of Potonié, which are found in many ponds and in lakelets within peat swamps. They, like the other coals, are composed of changed plant material, but they frequently contain animal remains.

All coals have more or less inorganic material, the ash or incombustible portion. At times the quantity is insignificant, less than 1 per cent. but it often exceeds that of the combustible matter, in which case the rock is known not as coal but as carbonaceous or bituminous shale.

The Extent of Coal Deposits.

The areas of individual coal deposits vary from a few square yards to many hundreds of square miles. Those of very limited extent are, usually, outlying patches, occupying spaces eroded in older rocks and they abound in some of the western states, where the coal rests unconformably on beds of Mississippian or even greater age. Hall[8] described several in Iowa, most of which consist of

[8] James Hall, Rep. Geol. Surv. Iowa, 1858, Vol. I., pp. 121, 124, 126, 130, 131, 133; A. H. Worthen, ibid., pp. 212, 223, 234.

impure cannel. Worthen found many. They are from 150 feet to 2 or 3 miles in diameter, contain well-defined underclays with more or less coal. In one, the coal dips to the center of the little basin; in another, the coal thickens toward the center; in others, the coal is irregular, but in all the coal thins out in approaching the border. At one locality, marine limestone rests directly on the coal. Bain[9] has discussed these localized deposits and has explained the concave upper surface of the coal as due to consolidation of the vegetable material.

Similar small basins are numerous in Missouri, directly south from Iowa, and occasionally they are of commercial importance. Swallow[10] says that some contain cannel, others, ordinary coal; but the noteworthy feature is that in all the deposit is thick. In one he saw 20 feet of good coal underlying 6 feet of cannel. Meek examined several in undisturbed Mississippian beds and others which occupied hollows in Silurian limestones. Impure cannel is the prevailing material but he saw good coal in one basin. Later observers have gone more into detail. Potter[11] described a basin, only 200 yards in diameter, which yielded 22,000 tons of coal; it had two coal beds, 2 and 16 feet thick. Another, 115 yards in diameter, yielded 3,730 tons; its coal bed, with maximum thickness of 8 feet, thinned away on the borders. One, examined by Winslow, occupies a hollow in the Magnesian (Lower Ordovician) and holds a coal bed, almost 7 feet thick midway, and roofed with 7 inches of clay, on which rests fossiliferous calcareous shale. More remarkable pockets were described by Ball and Smith and were thought by them to occupy "sink holes." In one case, the diameter is somewhat more than 270 feet, while the depth is more than 130. Shale, 38 feet

[9] H. F. Bain, Iowa Geol. Surv., Vol. VII., 1897, p. 300.

[10] G. C. Swallow, First and Second Ann. Reps. Geol. Surv. Missouri, 1855, Part I., pp. 191–193; F. B. Meek, ibid., Part II., pp. 112–114; Reps. Geol. Surv. Mo., 1855–1871, 1873, pp. 132, 149.

[11] W. B. Potter, "Preliminary Report on Iron Ore and Coal Fields," Geol. Surv. Mo., 1873, pp. 271–274; A. Winslow, "Preliminary Report on the Coal Deposits of Missouri," 1891, pp. 168–171; S. W. Ball and A. F. Smith, "Geology of Miller County," Bureau of Mines, Vol. I., 1903, pp. 100, 105, 107, 108, 111.

thick, is at the bottom and on it rests bituminous coal, 32 feet. The coal in all the pockets is rather impure. Meek thought that the coal beds had been let down by solution of the underlying limestone, but studies by later observers make evident that the accumulations were deposited in preëxisting hollows.

Ashley[12] described a small area occupying a basin of different type, eroded in the Merom sandstone of Sullivan county, Indiana. This is in the upper part of the Coal Measures and is regarded by him as evidence of a land surface. The coal is thickest in the middle of this basin and thins away in all directions toward the border. The lower coal beds in Indiana exhibit a tendency to this basin shape, the thinning of coal toward borders of the "swamps" being a common feature. But higher in the column, the areas increase and at length the coal beds are practically continuous for long distances.

The condition, noted by Ashley in Indiana, prevails in the northern part of the Appalachian basin, where extreme irregularity decreases after the close of the Pottsville, and the coal becomes reasonably continuous in greater areas, so that mining enterprises are attended by less risk. But the irregularity was very great in the Pottsville. Reference has been made in another connection to Roy's description of the mode in which the Sharon coal bed occurs, which confirmed the statements made by Newberry, Read and others in the Ohio reports. The same features characterize the Beaver beds in Pennsylvania, of which Ashburner[13] says that in the northern counties of the state they occur in "swamps," "swallows" or "sumps," and that they are saucer-shaped; the coal thins to a knife-edge on the hillocks of sand but is reached again when those have been pierced. I. C. White[14] was able to study the vagaries of the Sharon coal bed in a mine with 10 miles of workings. The coal rests on 1 to 2 feet of fireclay, overlying the Sharon sandstone.

[12] G. H. Ashley, "The Coal Deposits of Indiana," 23d Ann. Rep. Geol. Surv. Ind., 1899, pp. 22–24, 532, 633, 666, 909.

[13] C. A. Ashburner, Sec. Geol. Surv. Penn., Rep. *R*, p. 53; Rep. *RR*, pp. 95, 97.

[14] I. C. White, Sec. Geol. Surv. Penn., Rep. *Q*, pp. 194, 202; Rep. *QQ*, p. 170; Rep. *QQQ*, p. 123.

The floor is uneven, characterized by "hills" and "swamps," the coal being 4 to 5 feet thick in the latter but thinning away to almost nothing on the former, which are merely piles of pebble rock, rising at times with a slope of 15 degrees. The "swamps" are depressions among the "hills," which White thinks are due to erosion, as the pebble rock varies from 6 to 25 feet, the least thickness being under the swamps. This condition occurs less commonly in higher beds, but it is by no means rare. The Lower Kittanning, in Lawrence county, rests on an uneven floor of fireclay which has an extreme thickness of 10 feet. The coal often dips into swamps with increased thickness at the rate of one foot to the yard; it decreases usually about one half on the hills. The reports by Chance and W. G. Platt note similar conditions in other coal beds of the Allegheny; these are only too familiar in the Conemaugh.

Are Coal Beds Continuous?

The query at once presents itself, are these petty areas exceptional or are they typical? They are from a few yards to several miles in diameter, and one might expect to find yet larger areas, distinctly limited. The question is of great economic importance and the answer is of equal importance in relation to the problem in hand. Are coal beds continuous or do the names applied to them designate only horizons, marking periods when accumulation of coal took place, so to say, contemporaneously at many places and in extensive areas?

The question has been raised less frequently in Europe than in the United States because the coalfields are of comparatively small extent. But in the bituminous region of the Appalachian generalizations presented long ago still hold in the nomenclature, though some observers have opposed them strenuously. The early surveys were made when the region was thinly settled, when mining operations were unimportant and exposures of coal beds were mostly in small pits opened for local supply. There were few records of shafts, there were no records of borings and there were few graded roads; the section was worked out laboriously from natural exposures and without aid of the instruments now regarded as an

essential part of the geologist's equipment. The writer had as his duty, almost 40 years ago, the work of studying in greater detail extensive areas examined 30 years before by pioneer laborers in the northern part of the Appalachian basin. He has never been able to restrain the feeling that the work of those early geologists bordered on the miraculous—the intuition of Hodge, Jackson, Henderson and J. P. Lesley seems to him almost more than human. Even at the time of revision by geologists of the Second Geological Survey of Pennsylvania, the conditions, though better, were poor enough; dependence had still to be placed mostly upon natural sections, for the great mining industry was still in infancy and deep borings for oil were unknown. The defective conceptions inherited from the preceding generation were accepted and continuity of coal beds was taken as the fact, barren areas being regarded as exceptional. This belief was strengthened by the known distribution of the Pittsburgh coal bed, which appeared to have been proved within an area of not far from 15,000 square miles. But the multitude of shafts, the vast number of oil-well records, the increased number of natural exposures due to railway and road construction have provided data during the last twenty-five years, which compel modification of opinion.

When I. C. White, after study of oil-well records in West Virginia, announced that the Pittsburgh coal is wholly absent from fully one half of the area enclosed within the outcrop, the announcement was received with surprise. Stevenson, nearly twenty years earlier, had reached the conclusion that the Allegheny coal beds, for the most part, were wanting in the interior portion of the bituminous region, but White's study of the well records gave the evidence. There is a continuous area of about 10,000 square miles in which coal accumulation was very irregular from the end of the Pottsville to the close of the Carboniferous. But the irregularity is not confined to the central area; it is characteristic, to a less extent, of the whole region.

The conception of continuity was a normal conclusion from the available facts. A coal bed was generally found almost directly under the Mahoning sandstone, resting on a fireclay which overlay

a limestone. Many times an exposure was incomplete, some portion of the little group was concealed but enough was seen to make recognition definitive. The coal was observed so often that, when its place was concealed, its presence was assumed. The bed was mined at that time near Freeport in Pennsylvania and the deposit was named Upper Freeport. Either coal or very black shale was exposed so often in this position both in Pennsylvania and Ohio that barren spaces were regarded as due merely to petty local conditions and the supposedly continuous deposit was called the Upper Freeport coal bed. In like manner, the other horizons became known as coal beds and widespread accumulation of coal at each horizon an accepted fact, without reference to either quantity or quality of the material.

But detailed study of individual coal beds proves that in all there was great irregularity. The Pittsburgh, Waynesburg and Washington, in the upper portion of the series, approach as nearly to continuity as one may conceive, for they are always present in exposures and records within an area of thousands of square miles; but the Pittsburgh shows remarkable variations in thickness; it thins away to nothing from all sides toward the central part of the area while at times only its underclay remains to mark the horizon. The Waynesburg and the Washington horizons are persistent, coal or black shale being present, but there is often only a trace of coal, while the variations in structure of the deposit are extreme. Some Conemaugh coals are practically continuous, according to natural exposures, in Ohio within an area of not far from 1,000 square miles, but they are rarely seen in Pennsylvania; others are present on the east side of the region and rarely appear on the west side. The Allegheny conditions are similar; one bed attains great commercial importance within an area of perhaps a thousand square miles in Ohio, but in Pennsylvania and West Virginia, it is only occasionally important and it is practically wanting in considerable areas. And the statement is true of other coal horizons. The evidence goes to show that there were periods, longer or shorter, during which proper conditions existed, so to say, contemporaneously in many localities but did not exist in very many others. The

greatest unbroken area, after the close of the Pottsville, in which coal accumulated, was that at the Pittsburgh horizon, the coal having been proved up in an area of approximately 8,000 square miles. Originally it was greater, for erosion has removed much. The Sewanee coal bed of the New River seems to have a great continuous area, but the measured sections are somewhat widely separated; they suffice to prove identity of horizon, but they do not justify either assertion or denial of continuity.

Accepting, however, the extreme conceived area for original extent of the Sewanee or the Pittsburgh, one is compelled to recognize that accumulation of coal was not in process at any time in an area of more than 30,000 square miles and that it never was in process simultaneously in all parts of that area; that at most horizons, conditions were favorable to accumulation in areas of a few square miles to some hundreds of square miles while in perhaps the greater part of the regions the conditions were unfavorable. In fine, that the conditions were very much like those existing to-day. And this has always been the case. The Triassic coals were formed in narrow areas; the inconstancy of Upper Cretaceous coals in New Mexico, Colorado and Utah is proverbial—they are spoken of as lenticular; Tertiary brown coals exhibit the same features, which are equally characteristic of Quaternary deposits as well as of peat accumulations of this period. At all periods, conditions favorable to accumulation of coal have existed in comparatively small areas, more or less widely separated. This will be considered in another connection.

The relation of coal to the immediately adjacent rocks is so intimate that they must be regarded as one: a coal bed consists of the floor, mur, Liegende; the coal, houille, Kohle; the roof, toit, Hangende, each of which must be examined in detail.

The Floor of the Coal Bed.

Miners, long ago, recognized that coal beds ordinarily have a clay floor or seat, but the fact was announced as generalization first

by Mammatt[15] after his study of the Ashby-de-la-Zouche basin. Logan[16] reached the same conclusion independently, several years afterward, as the result of studies in south Wales. His statements led to a comparison of notes and the conditions seemed to be the same everywhere. The relations of the Illinois coal beds have been cited as evidence that the condition is by no means general, but the citation is an error, for Worthen's[17] remarks are so clear that one is at a loss to comprehend how the error came about. He says

The typical fireclay, the "underclay," "seat," or "mur" is rather fine in grain, somewhat sandy, very light gray to almost black, the tint depending on presence or absence of vegetable matter. Carbonate of iron is almost invariably present, sometimes in very small quantity but many times it is abundant in nodules. Alkalies are comparatively unimportant, though often present in sufficient quantity to unfit the material for firebrick. Ordinarily, the rock is plastic, but occasionally it is hard and non-plastic, a "flint clay." This clay seldom shows lamination and on exposure to the air it breaks up quickly into irregular angular fragments. The remarkable feature is the presence of *Stigmaria,* whose rhizomas are often interlaced in very complex manner. Owing to the abundance of the plants, the clay is often termed *Stigmaria*-clay; but the presence of that plant is not essential; where *Sigillaria* and *Lepidodendron* are wanting or of rare occurrence, *Stigmaria* is absent. It has not been reported from underclays of the Monongahela or higher formations in the Appalachian basin.

The "coal-seat" is not always clay or even impure sandy clay.

[15] E. Mammatt, "Coal Field of Ashby-de-la-Zouche," 1834, p. 73.

[16] W. E. Logan, "On the Character of the Beds of Clay, Lying Immediately Below the Coal Seams of South Wales," *Proc. Geol. Soc. Lond.,* Vol. III., pp. 275, 276.

[17] A. H. Worthen, Geol. Surv. Illinois, Vol. I., 1866, p. 59.

"The coal seams are usually underlaid by a bed of fireclay, which varies in thickness from a few inches to ten or twelve feet. This was the original soil on which the vegetation that formed the coal grew, and it is often penetrated by the rootlets of the ancient Carboniferous trees, whose trunks and branches have contributed to form the coal."

Hantken[18] gives a section at a Hungarian locality showing 8 coal beds from 0.15 to 3.10 meters thick, of which four have clay and four have sandstone as the floor. Coal deposits were formed on clay, shale, sandstone or even limestone, the conditions being apparently the same as those observed in the study of peat accumulations. The Triassic coal of the Richmond area in Virginia was long supposed to rest on granite. Taylor[19] mentioned the recognized fact that the coals of that area rest directly on granite, though occasionally a foot or two of shale may intervene. Bosses of granite rise as eminences and interfere with mining. This opinion was shared by W. B. Rogers in 1843 and at a later date by Lyell, who asserted that the lower coal bed is in contact with the fundamental granite. The true condition was ascertained by Shaler and Woodworth,[20] who showed that the granite contact is due to faulting and that, normally, there is a notable interval, sometimes 300 feet, filled with barren rocks. There is no *a priori* reason, however, why coal might not accumulate on a granite seat. Chevalier's description of the peat growth on granite and gneiss in the Niger region makes this clear enough.

Cores from diamond drilled holes in the anthracite areas of Pennsylvania indicate in many cases that coal beds of notable importance rest directly on conglomerates or are separated from them by a mere film of clay. The cores show all gradations in the floor from fine clay to conglomerate. Similar conditions exist elsewhere. The hard silicious rock, known as "Ganister,"[21] is at times in contact with the overlying coal bed in the Yorkshire field. Sections in other British fields show that a sandy floor is a by no means uncommon feature, though clay is the usual material.

Limestone of marine or freshwater origin is frequently the floor

[18] M. Hantken, "Die Kohlenflötze und der Kohlenbergbau in den Ländern der ungarischen Krone," Budapest, 1878, p. 131.

[19] R. C. Taylor, "Memoir of a Section Passing through the Bituminous Coal Field near Richmond in Virginia," *Trans. Geol. Soc. Penn.*, Vol. I., Part II., 1836, pp. 286, 287.

[20] N. S. Shaler and J. B. Woodworth, "Geology of the Richmond Basin, Virginia," 19th Ann. Rep. U. S. Geol. Surv., 1899, Pt. II., pp. 424–426, 429, 430.

[21] A. H. Green, "The Geology of the Yorkshire Coal Field," 1878, pp. 19, 26.

of a coal bed. Several coal beds in the Monongahela and higher formations within the Appalachian basin rest at times on fresh-water limestone or calcareous shale; at others clay or shale intervenes, so that in different parts of the area the same coal rests on clay, shale, sandstone or limestone. Two coals of the Conemaugh in Ohio show similar relations to a marine limestone, sometimes in contact with it, at others, separated by several feet of shale or other material.[22] C. Robb in 1876 reported 6 inches of limestone directly under a Canadian coal bed, and J. W. Dawson in 1868 described a coal bed which overlies a bituminous limestone, containing *Naiadites* and *Stigmaria,* the latter, in his opinion, being evidently in place. Not many instances of coal resting directly on marine limestone are recorded from the Appalachian basin, because, with one exception, the marine limestones are, geographically considered, very unimportant members of the column. Nor is the occurrence frequent in any field, so far as the writer can discover, though there are many localities where the interval is not more than a foot. Worthen states that the Coal 1 of Illinois usually overlies 2 to 3 feet of fireclay, but the fireclay is often absent and the coal rests directly on the St. Louis limestone. This, however, is not of the type under consideration, for the case is one of pre-Pennsylvanian erosion; the Illinois Coal 5 occasionally rests on a nodular limestone and Coal 6 is frequently in contact with the underlying marine limestone. Ricketts has described a number of coal pockets in Lower Carboniferous limestone of England but they do not concern the matter in hand, for they are clearly like the Iowa and Missouri pockets, in cavities eroded when the limestone was above water.

Crampton,[23] however, has given notes which do concern the matter. Presenting the results of studies in East Lothian, Scotland, he refers to the lowest limestone as essentially a coral reef with an abundant marine fauna. Portions of the surface were converted

[22] J. J. Stevenson, Sec. Geol. Surv. Penn., Rep. *K*, 1876, pp. 94, 96, 116, 270, 349; Rep. *KK*, 1877, pp. 52, 163, 179; "Geology of Ohio," Vol. III., 1879, pp. 183, 211, 224, 240, 256.

[23] C. B. Crampton, "The Limestones of Aberlady, Dunbar and St. Monans," *Trans. Edinb. Geol. Soc.*, Vol. III., 1905, pp. 374–378; "Fossils and Conditions of Deposits, a Theory of Coal Formation," ibid., Vol. IX., p. 74.

into white marl, consisting of pulverized coral. In most places, where the horizon is exposed, a coal bed is seen overlying this reef and often in direct contact with the limestone. Great branching *Stigmariae* grew upon the rock, following all irregularities of the surface as they pushed their way through the marl. Limestone under brown coal is reported from the Tertiary[24] as well as from the Quaternary and it occurs frequently under peat deposits of the Recent period. Evidently, *Stigmaria* cared less for the soil than for other conditions, just as do many plants of this day. The relations of coal to the seat are very like those observed in peat deposits, where the accumulation may begin on clay, sandstone, limestone or even on bare consolidated rock, if only the essential condition of moisture be present. Temperature is not all-important, for peat accumulates as well in the tropics as in the temperates, wherever peat-making conditions exist. It fails in the tropics precisely as it does in the temperates, when the peat-making conditions are absent. The relations were the same in earlier periods, for Wall and Sawkins[25] report their discovery of 37 coal beds in the Miocene of Trinidad, of which 5 are workable, with a thickness of 19 feet; and this coal-bearing formation was followed by them on the mainland in an area of 36,000 square miles. And the condition still exists on that mainland. Harrison[26] says that tropical peat, known as "pegass," occurs behind the fringes of courida and mangrove in many parts of the low-lying coast lands of British Guiana and that it is from 1 to 10 feet thick, though usually 2 to 4 feet. He pointed out that, on the pegass land, the alternation of wet and dry seasons allowed both marsh and ordinary plants to grow and that considerable areas were covered with forest of the Aeta palm.

Stigmaria is present in a great proportion of the underclays. The manner of its occurrence has been described on earlier pages and only passing reference is needed here. Sorby, Platt and Daw-

[24] C. v. Gümbel, "Beiträge," etc., pp. 149–151; O. Heer, cited in "Formation of Coal Beds," these PROCEEDINGS, Vol. L., p. 623.

[25] G. P. Wall and J. G. Sawkins, "Report on Geology of Trinidad," London, 1860, pp. 112, 197.

[26] J. B. Harrison, "Pegass of British Guiana," *Quart. Journ. Geol. Soc.*, Vol. LXIII., p. 292.

kins have testified that, in the cases described by them, the arrangement of the rhizomas proved not only that the plants are *in situ* but also that the direction of prevailing winds was the same during the Carboniferous as now. The immense extent of roots, spread out in normal attitude, as in the plants described by Adamson, Williamson, Potonie and others, compels those students to assert that no conceivable mode of transportation can explain the phenomenon. The interlacing of the roots, shown by Schmitz, Crampton and many others, is regarded as affording strong confirmatory evidence of *in situ* growth. Many coal beds are divided by clay partings of variable thickness; *Stigmaria,* at times, occurs abundantly in such partings. Robb's remarkable specimen was rooted in such a lens of fireclay. But *Sigillaria* and *Lepidodendron,* to which *Stigmaria* belongs, are not the only coal-making plants; just as peat is composed of many plants or of different assemblages of plants in various parts of the world, so coal in one area was formed of plants unlike those in another. There are great coal deposits containing no *Sigillaria* or *Lepidodendron* and consequently the underclay is without *Stigmaria.*

Occasionally rootlets are found so arranged as to make certain that the materials had suffered no disturbance. Ward,[27] visiting the Saint-Etienne coal field after the Geological Congress of 1900, saw many instances in which the finest fibrils of roots of erect *Calamites* passed across the planes of bedding down the conglomerate, which formed the original floor; the condition was regarded by him as incompatible with the slightest movement. Bertrand[28] observed rootlets *in situ* in an underclay within the Grande Couche at Decazeville; and the writer saw threads of coal descending into an underclay in the upper part of the Campagnac coal bed of the same basin, which suggested rootlets. Fox-Strangways[29] states that he saw rootlets passing downward from the Four-

[27] L. F. Ward, "The Autochthonous or Allochthonous Origin of the Coal and Coal Plants of Central France," *Science,* N. S., Vol. XII., 1900, p. 1005.

[28] P. Bertrand, in letter of January 15, 1911.

[29] C. Fox-Strangways, "Geology of South Leicestershire and South Derbyshire Coal Field." *Mem. Geol. Surv.,* 1907, p. 52.

foot coal into the underclay. D. White, in a letter, says that, during his studies in Kansas and Missouri during 1912, he failed at only one mine to find satisfactory evidence of roots *in situ* in the underclay. At one locality in Kansas, the sandy fireclay contains beautifully preserved interlaced vertical roots while at others in both states absolutely good roots are present.

Bennie and Kidston[30] found spores abundant in underclays, especially within the first 2 or 3 inches below the coal; they cite two localities in which the lower part of the thin clay is barren while the upper portion contains the forms abundantly.

Underclay without coal is by no means rare. Sometimes it underlies black shale with plants *in situ;* in some cases it alone marks the horizon which elsewhere shows a coal bed. In other cases, it is a "forest bed," marking a locality where conditions did not favor accumulation of plant material or where the coal was removed by erosion. Dawson has described many of these and Grand'Eury says that the phenomenon of vegetable soils is as familiar in the Loire basin as it is in Canada. Strahan[31] has given a recent illustration. In the new South Dock excavation at Cardiff, 11 feet of gravel underlies 19 feet of brown and blue clay with some sand. In this gravel were found several upright stumps, about 2 feet high, "rooted in a black clay with stems, the roots extending down into the red marl."

Boulders have been found in the underclay. Ashley[32] states that the underclay of Coal IV. is soft and fine but, in places, full of bowlders. This is the only American record, aside from an incidental note by Gresley, that the writer has discovered, but he has been assured that waterworn fragments do occur in the underclay. Apparently they are not numerous enough at most places to attract attention and the occurrence may be regarded as infrequent. Most probably, the pebbles were laid down on the river plain prior to

[30] J. Bennie and R. Kidston, "On the Occurrence of Spores in the Carboniferous Formation of Scotland," *Proc. Roy. Phys. Soc. Edinb.*, Vol. IX., 1888, pp. 102, 103.

[31] A. Strahan, "Geology of South Wales Coal-Field," III., 1902, p. 94.

[32] G. H. Ashley, "The Coal Deposits of Indiana," 23d Ann. Rep. Geol. Surv. Ind., 1899, p. 543.

deposition of the clay, which filled the interstices, so that they may be sought in thin deposits or at the bottom of those which are thicker.

Underclays are often very light in color and many of them contain little iron and less carbon; but some iron is always present even in the most refractory. There is similar variation in the content of alkalies. The absence of iron is believed to be due in chief part to decaying vegetation. The deep red shales of the Coal Measures contain little organic matter, few traces of plants or animals. That organic acids, formed during decomposition of vegetable materials, give somewhat soluble salts with iron has been known for a long time, as was shown on earlier pages where are recorded the results obtained by A. A. Julien and others. Miller,[33] in describing the Boulder Clay of Cromarty, Scotland, gave a local illustration. On the flat moor upland, where the water stagnates over a thin layer of peaty soil, chance sections exhibit the underlying clay spotted and streaked with grayish-white patches. There is no difference between these patches and the red mass in which they occur, all alike consisting of mingled arenaceous and aluminous particles. The stagnant water above, acidulated by its vegetable solutions, seems to be connected with these appearances. In every case, where a crack gives access to the oozing moisture, the clay is bleached for several feet downward to nearly the color of pipe clay. The surface, too, wherever divested of the vegetable soil, presents for yards together the appearance of sheets of half bleached linen. Dawson[34] observes that underclays have the white aspect which one sees in the subsoil of modern swamps, and he thinks that the cause is the same in both cases—the removal or transportation of ferruginous coloring matters by the deoxidizing or dissolving action of organic acids or of organic materials in decomposition.

Stainier[35] has taken exception to this statement of the conditions and has shown that of 150 specimens of Begian underclays, barely a

[33] H. Miller, "The Cruise of the *Betsy*," Boston, 1862, p. 357.

[34] J. W. Dawson, *Quart. Journ. Geol. Soc.*, Vol. X., 1854, p. 14.

[35] X. Stainier, "Notes sur la formation des couches de charbon," *Bull. Soc. Belge Géol.*, Vol. XXV., 1911, P. V., pp. 73–91.

dozen failed to become distinctly red on burning. Those which failed were mostly sandy and two of them were typical "fire-clays." He has found that carbonate of iron frequently occurs as kidneys in the mur—indeed he regards the presence of such kidneys as in some way characteristic of the mur. The immediate provocation for Stainier's discussion was the statement by Mourlon[36] that "the mur represents the soil on which grew the now buried and metamorphosed forests of the coal epoch. The forests then as now had the property of taking away the iron disseminated in the soil." It is certain that Mourlon and Dawson, in their generalized statement, have written with too little reserve, for neither one of them could have intended to assert that vegetation had removed all iron from the clay. One reading Dawson's publications sees at once that he was familiar with the occurrence of clay ironstone kidneys in underclays. Stainier says correctly that, if coal be of *in situ* origin, the iron should be returned to the soil when the trees die; but it is evident that he reasons from conditions existing in an upland forest, which are as a rule very different from those upon which the *in situ* doctrine insists. Vegetation undergoing chemical change in swamps does not disappear but becomes peat; only a very small part of the inorganic matter could find its way back to the mur; it would remain in the peat. The mur is merely the soil in which the vegetation began; before long, the decomposing plant material becomes the soil and all relation to the mur ceases. The conception that trees cannot thrive in or on peat is a curious survival, which retains its place in argument although it is contrary to fact. As has been shown in an earlier part of this work, the plant life of swamps is not confined to mosses and humble plants but it includes large shrubs and great trees. Among the latter are some of the noblest forms on the American continent, which certainly thrive as well in swamps as on drier land. Very many plants cannot live on the acid soil of peat, but there are very many others which cannot thrive on soil of any other type. As will appear on a later page, accumulation of peaty matter makes possible only indirect action on the mur or original soil, and that is due only to the

[36] M. Mourlon, "Géologie de la Belgique," Bruxelles, 1880, Vol. I., p. 121.

sinking of dissolved humic and other organic acids, which reaching the bottom may remove iron and alkalies from the clay as they do from the peat. If the original quantity of iron in the mur was small, all or practically all might be removed; but if large, the greater part would remain. In any event there would be a chemical change and the color would become lighter, though enough iron might remain to become distinct after burning.

The tinting of underclays depends in great measure on the quantity of carbon present. Changes during conversion would remove some vegetable matter, but not much, for drainage would be chiefly along the surfaces of roots, which may account for the lack of a coal crust, so often observed in *Stigmaria*. The removal could not be extensive throughout the mass, so that if the original quantity was considerable, the clay would be blackened.

The suggestion has been made that gray or whitish murs are not common and that the tint is not original, for, at some distance from the outcrop, the color is not distinctive. The light-colored English clays, it is stated, have been exploited only along the outcrop, where the passage of pluvial waters would be able in time to remove the coloring substances. How effective this pluvial leaching would be in material so nearly impervious as consolidated underclays, the writer cannot determine. On old outcrops of clays and clay shale at roadsides, he has found little evidence of removal of iron and carbon. There is usually a fixation of the iron while the bleaching, as a rule, is insignificant—usually apparent rather than real and due to disintegration or powdering. It may be that the English clays have been exploited only along the outcrop but the case is different in the Appalachian basin. The tints are not confined to the outcrop. Clays have been mined at several localities in Pennsylvania and Maryland during 30 to 60 years, while in Ohio and West Virginia similar work has been continuous for 60 to 80 years. Very many of the mines work up the dip and are "bone dry" with thick cover, at times hundreds of feet, through which no water passes. Pluvial leaching has not existed there. The clay in these mines at a few feet from the outcrop is like that obtained at 1,000 or 2,000 feet farther inside, with pockets of varying tint and of varying composition—the latter

often so serious that great care must be taken in selection for the manufacture of high grade fire-brick. A similar condition was observed in mines working down the dip, the only difference being that the effects of freezing and thawing were perceptible to a somewhat greater distance. H. Ries has informed the writer that the effect of weathering rarely extends beyond 15 feet in a horizontal bed of clay.

The source of the clays is not always clear. It is true that clay is not always present under coal beds, for those rest indifferently on clay, limestone, shale sandstone or conglomerate, just as modern peat bogs do, so that for present purposes the question of source is of subordinate importance. At the same time, it is not without interest, for in a great proportion of cases, conditions favoring accumulation of coal followed those favoring deposition of clays. Firket's[37] observations have been cited frequently as showing that atmospheric water can convert shale into plastic clay and in support of the suggestion that underclays may be due to changes after deposit. Near Liége a shaft, 30 meters deep, reached an ancient mine which had been abandoned probably 700 years before. There the succession, descending, was Psammite, 0.95 m.; Gray plastic clay, 0.40 m.; Shale, not measured. The clay is very similar to the refractory clay of Ardenne. The psammite had given way, was broken and atmospheric water was admitted, which gave to that rock a brown tint while it changed the upper part of the shale into refractory clay. At another locality, the psammite in ancient workings had become sandy micaceous clay and the shale had become converted into black clay. Firket concluded that, under some circumstances, shale rocks may undergo considerable alteration *sur place.* The action of true mineral springs is not required to effect change of shale into clay, but infiltration of pluvial waters penetrating the ground across a small thickness of rocks may have an influence. It is unnecessary in that case to have the action extend over a long period in order to change 0.40 meter of shale into plastic clay, for not more than 700 years had passed since the ancient mines were abandoned.

[37] A. Firket, "Transformation sur place du schiste houiller en argille plastique," *Ann. Soc. Géol. de Belgique*, Vol. I., 1874, pp. 60–63.

The observations by Firket are not without interest but, as he recognized, they have little bearing on the matters at issue here. Shales ofttimes are merely laminated clays and lose their lamination when exposed to the atmosphere. There are many roads in the Appalachian basin which show deep through cuts in argillaceous shale. Less than a century, frequently much less than half a century has passed since the roads were constructed, yet the period has sufficed for conversion of the outcrops into plastic clay. But that is not the question. The Lower Kittanning coal rests on a bed of plastic clay, 10 to 20 feet thick, an excellent potters clay, used in manufacture of various wares along a line of more than 150 miles in Pennsylvania, Ohio and West Virginia; a flint clay at the base of the Allegheny, 5 to 25 feet thick, is utilized at many places along a line of fully 100 miles in Maryland and Pennsylvania. No condition such as that described by Firket seems likely to afford even a suggestion toward explaining the accumulation of such deposits, which, except as to thickness, are typical. Nor can one find sufficient explanation for the small proportion of iron in activities of plant life, since those could affect only the superficial portion. The features seem to be original in the mass and due to the work of atmospheric agencies prior to deposition. Long exposure of rocks causes deep distintegration and decomposition, as has been proved by Russell Crosby and Belt, already cited in another connection. The widely distributed Kittanning clay followed the Vanport subsidence, which had been preceded by a long period of quiet or of local elevation, during which deep valleys were eroded on the west side of Alleghania and, in an extended area, no new deposits were laid down. When the disintegrated materials were removed, the finest clays were deposited by themselves, carrying with them the impalpable humus of the soils. The strange irregularities, exhibited by beds in the closing portion of the Beaver, are evidence of a similarly long exposure for great areas and afford reason for applying the same explanation to the other great deposit. The condition may have been similar elsewhere and may account for clays under coal beds as well as at horizons where deposition of clay was not followed by conditions favoring accumulation of coal.

The Coal.

The passage from mur to coal is gradual at most localities; but it appears to be rather abrupt where the seat is a sandstone or conglomerate. This latter statement is made with reservation, as the writer has had few opportunities to make determination, since coals with sandstone floors are seldom of economic importance within the areas which he has studied. No rèference to the condition appears in the literature to which he has had access; but the records of cores in the anthracite area lend countenance to the suggestion, for in many cases, a mere film of clay separates the coal from sandstone or conglomerate and the coal is good to the bottom. At some localities in the bituminous region, a coal bed is clean apparently to the contact with underclay, but in most cases the bottom coal is so impure as to be unmarketable. For the most part, one finds a transition layer, the *faux-mur,* between coal and clay; it may be very thin or it may be several inches thick, and it may consist of inferior coal or of coaly shale.

In broad areas, where the faux-mur is distinct, there is, nevertheless, an abrupt separation of the coal bed from the underlying clay; but this is not original, it is the result of disturbance. One finds this condition even in the western part of Pennsylvania and eastern Ohio, where the rocks vary so little from the original horizontality that the dips on the sides of the low anticlinals rarely reach half a degree and often for long distances are much less. Yet even there one finds that the coal has slipped under the pressure and that the contact between coal and clay is slickensided. This is the familiar condition everywhere, so that one seldom is able to determine the exact relation of coal to mur or the relation between plants of the mur and those of the coal. But the opportunity fell to the lot of Grand'Eury[38] during his study of the Loire basin. He says that in coal beds, at their mur and in their more or less shaly partings there are roots belonging to various species and that many a time he had

[38] C. Grand'Eury, "Du bassin de la Loire," *C. R. VIII^{e} Cong. Géol. Int.,* 1900, pp. 531, 532; "Sur les conditions générales et l'unité de formation des combustibles mineraux de tout âge et de toute espéce," *Comptes Rendus,* Vol. 138, 1904, pp. 740–744.

seen rhizomas of ferns and creeping roots of *Cordaites* making part of the coal, thus binding the beds to the vegetation of the mur—which, as he says, contradicts one of his former determinations. The lower portion of the coal in such cases is irregular in structure but the passage from one grade of coal to the other is gradual and the coal throughout is composed of the same plants. His belief is that the running rhizomas at the bottom of the marsh have formed coal in place, along with the fossil humus, which he regards as formation of peat, by which the rooted plants were killed, the stems and adventive roots being found in the coal above.

The thickness of a coal bed is from a film to many feet. Definite coal beds, not more than 6 inches to a foot thick, sometimes mark a horizon over hundreds or even thousands of square miles. A thickness of more than 8 feet is unusual in the bituminous regions of this country but very much greater beds are reported from some fields in Europe. The Grande Couche of les Pegauds in the Commentry basin attains, according to Fayol, a maximum of 12 meters while the main bed of the other subbasin reaches, at one place, 20 meters. The vast deposits at Decazeville are in each case at least 70 feet thick near that city and apparently about 100 feet at a few miles south. Dannenberg gives the thickness of one bed in Saarbruck as 5 meters and of the great bed in the Upper Silesian field as from 10 to 20 meters. The Mammoth bed of the southern anthracite field attains a maximum of 114 feet at the easterly end, including only 9 feet of partings. In this case, as also in that of the great Reden bed of Upper Silesia, the enormous thickness is due to union of several beds by disappearance of the intervening rocks. Coal in any field makes up but a small part of the total section. In the middle division of the Saarbruck measures, there are said to be 132 coal beds, in all 32 or 33 meters thick, within a column of 850 meters; in the bituminous region of Pennsylvania, the column is somewhat more than 4,000 feet and contains perhaps 30 coal beds with total thickness of 110 feet.

Variations in Structure.

A coal bed is apt to vary rather abruptly in structure, local conditions having been as efficient during accumulation of coal as they are now during accumulation of peat. A coal bed may consist of two or more divisions, the benches or bancs, separated by partings, which are often more variable in thickness and composition than the coal itself. In some treatises, these benches are referred to as separate beds—and with good reason, as will appear after consideration of the varying character of the partings and the often contrasting composition of the coal in successive benches. Occasionally, however, definite structure persists throughout a considerable area. Thus the Pittsburgh bed, at the bottom of the Monongahela formation, shows roof division, overclay, breast-coal, parting, bearing-in-coal, parting, brick-coal, parting, bottom-coal.

This structure can be recognized in the northern part of the area along a west-northwest line of not less than 170 miles from the eastern to the western outcrop in Maryland, Pennsylvania and Ohio, exposures being practically continuous for 120 miles. It is distinct in an area on each side of the line not less than 40 miles wide for much of the distance and much wider on the eastern side. Yet even this remarkable bed, when traced beyond the limits given, shows that it too is variable. Bownocker[39] has made clear that on the western side, in Ohio, the structure changes abruptly at a little way south from the long west-northwest line. The change first appears in southern Belmont county, where the roof division disappears and the breast-coal becomes irregular. Within a few miles, the bed consists of coal, clay, coal, there being no recognizable trace of the upper 6 parts and the clay parting is often a foot thick, whereas in the typical section the partings are all thin, seldom more than half an inch. The condition, first observed in southern Belmont county, prevails southward on the western side for 90 miles. At some localities, the section resembles that seen farther north but analysis of the parts shows that they are not the same.

[39] J. A. Bownocker, Geol. Surv. Ohio, 4th Series, Bull. 9, 1908, pp. 10–12.

I. C. White[40] has given many measurements of the bed showing that similar changes are found in West Virginia along the eastern border, beginning at a few miles south from the Pennsylvania border. The Roof division is wanting almost at once, but that is due to erosion prior to deposition of the Pittsburgh sandstone, and at times one finds the bed complete where the roof was spared. At a little distance southwest, where the sandstone has thinned away, the changed section is distinct and the bed appears to be merely double. It is divided by "bone" or clay, 1 to 15 inches, and the benches vary greatly in thickness; at some localities the upper one has almost disappeared while at others the lower is almost wanting; here and there the bed has a section somewhat like that at the north but comparison of the parts shows that the resemblance is only apparent. The writer, nearly 40 years ago, thought that the change was merely apparent and that he could recognize all elements of the northern structure to a great distance south from Pennsylvania; but the many detailed measurements recorded by White make that position no longer tenable.

Study of measurements along the northern border of the bed prove a variability which was not considered important by the students who examined that area. W. G. Platt's[41] sections in Indiana county of Pennsylvania show that in the extreme northern outliers along the eastern side, the structure is clear, but the lower members are irregular, becoming indefinite at times, while the Breast-coal increases in importance. Measurements recorded by White and by Stevenson[42] in Allegheny and in northern Washington county show that in the outlying areas at the north, the structure is usually recognizable but that the bottom and brick are insignificant, the bearing-in not always distinct, while the breast, though variable, is the important portion. These changes are wholly in contrast with those already noted as occurring at the south in both Ohio and West

[40] I. C. White, Geol. Surv. West Virginia, Vol. II., 1903, pp. 168–190; Vol. II. *a*, 1908, pp. 659, 663, 665, and elsewhere.

[41] W. G. Platt, Sec. Geol. Surv. Penn., Rep. *HHHH*, 1878, pp. 162–164, 27.

[42] I. C. White, Sec. Geol. Surv. Penn., Rep. *Q*, 1878, pp. 152, 166, 177; J. J. Stevenson, ibid., Rep. *K*, 1876, pp. 275, 277, 285; Rep. *KK*, 1877, pp. 313, 322.

Virginia and indicate a different history for the bed in the two regions, showing that coal accumulation persisted for a much longer period at the north than at the south. The conditions afford no little justification for the recognition of each bench as an independent bed. The irregularities of surface indicated by variations in the lower benches at the north as contrasted with the general regularity of the breast or upper portion show that in all probability the area of accumulation increased landward toward the north by advance of the marsh area. But increasing slate partings of extreme irregularity indicate sufficiently that small streams often flooded the area with muddy water.

The continuous area of the Pittsburgh coal bed was estimated by H. D. Rogers[43] at 14,000 square miles, the space embraced within the outcrop. I. C. White,[44] however, after study of oil-well records of West Virginia and Ohio discovered that the bed is wanting in a rudely triangular space within those states and that the available area is not more than 8,000 square miles. As the coal approaches the central area of fine sandstones and red muds, the structure becomes unrecognizable and the bed thins to disappearance. The constancy of the Pittsburgh coal bed is apparent rather than real.

Abrupt changes in thickness and structure are the rule in all coal beds. They are not startling in the bituminous region, except to those who have invested in mines, since the beds rarely exceed 10 feet; but they are very notable in the southern and middle anthracite fields. At one locality in the former, the Mammoth coal bed has 105 feet of coal in 114 feet of measures; at 8,246 feet toward the east it has only 42 feet in 49 feet; in both the coal is concentrated, there being but ten members in each section; but, within a short distance, one finds 40 feet of coal in 53 feet of measures and the section consists of 43 members.[45] Variations of this type are reported from all coal areas in the United States and they are commonplace in Europe.

[43] H. D. Rogers, "An Inquiry into the Origin of the Appalachian Coal Strata," *Reps. Amer. Assoc. Geol. and Nat.*, Boston, 1843, p. 446.

[44] I. C. White, "Stratigraphy of the Bituminous Coal Field in Pennsylvania, Ohio and West Virginia," U. S. Geol. Surv. Bull 65, 1891, p. 64.

[45] C. A. Ashburner, "The Geology of the Panther Creek Basin," Sec. Geol. Surv. Penn., 1883, pp. 96, 98.

Bifurcation of Coal Beds.

Parallelism of coal beds seems to be regarded as a fundamental principle by some of those who have discussed the origin and formation of coal beds. It has been the subject of many papers in the United States, based on studies in the Appalachian and Mississippi coal fields. With one exception, the authors rejected the doctrine of parallelism, but most of them recognize that, in some extended areas there is parallelism along definite lines.

The partings between benches of coal beds are usually extremely variable but in some beds they show amazing persistence. The bearing-in bench of the Pittsburgh bed is from 3 to 6 inches thick and is bounded by partings which rarely exceed one half inch; yet these are present under more than 2,000 square miles, changing little in thickness or in composition. Ordinarily they consist of mineral charcoal and almost impalpable inorganic matter, but occasionally they have so little inorganic material that the coal appears to be continuous—but the partings are there and the benches retain their peculiarities. This persistence in character is, however, a strange exception and in most beds the variation is extreme.

The splitting or division of the Mammoth coal bed in the anthracite area has been proved not only by measured sections and drill cores but also by continuous workings, which often extend for many miles. In the northern part of the Eastern Middle, the Mammoth and the next bed below, the Wharton or Skidmore, are in contact, but within a short distance the parting has become 114 feet; in another part of the same field, the interval between the beds increases from 35 to 200 feet, the workings on each bed being continuous; the same beds are but 6 feet apart in the southern part of the Western Middle, but farther south, on the north border of the Southern, the interval increases gradually to 80 feet. The Mammoth itself divides. Near Shenandoah in the Western Middle it is a single bed, 40 to 60 feet thick, but within a short distance it is in 2 and then in 3 "splits" in a vertical space of 150 to 200 feet. In the Southern, the bed breaks up, reunites and breaks up again. Sometimes it is a single bed but within a mile it may be in 2 or 3 splits in a vertical space

of 175 to 214 feet.[46] The extreme variations in interval have been proved by continuous workings on the several splits. It is impossible to determine the relations of these changes in interval throughout the area, as erosion has been energetic in that contorted region and the coal beds remain only in a few deep troughs.

Illustrations are abundant in Europe. De Serres,[47] in his description of the little basin of Graissessac, says that the coal beds present great regularity as a whole and preserve their parallelism almost constantly. Nevertheless, one finds remarkable anomalies in some parts of the basin. Coal beds approach each other in some localities while in others they are far apart. At times the beds present the appearance of a fan, especially well shown in the mines of one concession; in some of those in another concession, coal beds 3, 5, 6, are almost united, though in other mines, No. 3 is most frequently at 30 meters from No. 4. When one considers that the whole basin is less extensive than the "outlying area" of Pittsburgh coal in Somerset county of Pennsylvania, he must be interested by de Serres's loyalty to the orthodox doctrine amid trying circumstances. Gruner[48] remarks that the parting of the Batardes coal bed is from 50 centimeters to 8 meters thick. In the middle portion of the Lower Saint-Etienne stage, beds 1, 2 and 4 coalesce with 3, which is very thick; but at times, 4 is separated from 3 by 24 meters of rock. Beds 3 and 4 are frequently united as are also 1 and 2. The area of this stage is little more than that of a township in one of the western states; according to the map, it does not exceed 40 square miles. Fayol[49] has shown that the Grande Couche of Commentry is one bed at the east side of the sub-basin but on the west side it is represented by 8 beds in a vertical section of more than 200 meters. Boulay and others have given illustrations from north France.

[46] The observations on which these statements are based have been summarized in "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 17, 1906, pp. 219–221.

[47] (M) De Serres, "Des terrains houillers du département de l'Herault," *Acad. Sci. Montpelier*, Vol. I., 1850, p. 384.

[48] L. Gruner, "Bassin houiller de la Loire," Paris, 1882, pp. 212, 220, 225, 226.

[49] H. Fayol, "Études," etc., p. 22.

Dannenberg[50] states that the Zach bed of the Zwickau (Saxony) area is usually from 1 to 4.5 meters thick, but in the western part of the field it is represented by 2 beds, separated by 8 meters of rock. At Planitz in the southwest, the Planitzer bed is 10 meters thick and the partings are very thin; but these increase toward the north and the 3 benches are in a vertical space of about 70 meters. He gives illustrations of similar type from other coal fields. The familiar instance is that described by Jukes.[51] The Thick bed near Bilston has about 30 feet of coal in 12 to 14 benches; followed northward, the benches separate quickly, so that within 5 miles, one finds the 30 feet of coal distributed in a vertical section of 300 feet, the several benches being independent coal beds separated by shales and sandstones. The Bottom and the New Mine beds divide in like manner. Instances in other British fields have been described by Dugdale, Howell, Bolton and several other observers.

If one consider coal beds separated by considerable intervals he finds equally interesting variations. The Upper Freeport and the Pittsburgh are separated by 350 feet at the western outcrop in Ohio, but that interval increases gradually toward the east until in Indiana county of Pennsylvania it is 600 feet. The Pittsburgh and the Waynesburg are 166 feet apart at the northern outcrop in Pennsylvania, but that interval increases southwardly to more than 400 feet in northern West Virginia. The increase is regular in the thickness of intervening intervals between the Pittsburgh and Upper Freeport, for, throughout, the Ames limestone holds its place approximately midway between the coal beds; but no such regularity of increase is shown in the interval between the Pittsburgh and Waynesburg. An excellent illustration of this irregularity is shown by comparison of two sections given by W. G. Platt[52] from Armstrong county, Pennsylvania, which are as follows:

These measurements are about 18 miles apart and the interval between the Upper Freeport and the Lower Kittanning is practically

[50] A. Dannenberg, "Geologie der Steinkohlen Lager," 1911, pp. 211, 212.

[51] J. B. Jukes, "The South Staffordshire Coal Field," 2d ed., 1859, pp. 18, 19, 25, 26.

[52] W. G. Platt, Sec. Geol. Surv. Penn., Rep. *H5*, 1880, pp. 215, 288.

Upper Freeport coal bed	7	0	2	6
Interval	60	0	54	0
Lower Freeport coal bed	1	0	1	0
Interval	65	0	35	0
Upper Kittanning coal bed	1 to 12	0	1	0
Interval	45	0		
Middle Kittanning coal bed	4	0	117	0
Interval	25 to 40	0		
Lower Kittanning coal bed	3	0	3	0
Interval	33		25	
Vanport limestone				

the same in both, while the intervening intervals show notable variation. If one should group the sections given in Platt's report he would find that while the two coal beds preserve an approximate parallelism, the relations of the intervening beds would be indicated by lines describing very irregular waves. This portion of the Allegheny formation shows the same approximate regularity and the associated irregularity in other parts of the region.

The instance recorded by Jukes[53] has always been regarded as exceptionally perplexing. The "Roofs coal" of the Thick bed at Dudley rests on the bench below or is separated from it by, at most, 2 or 3 feet of clay; but in going toward Bilston, one finds the interval increasing, 0, 10, 37, 55, 128, 118 and at length, 204 feet near Bilston—these changes taking place within a mile and a half. Near Dudley one finds the Brooch coal at 95 feet above the "Roofs coal," known there as the "Flying Reed," and 108 feet above the Thick. But where the "Flying Reed" is 115 feet above the Thick it is only 30 feet below the Brooch; so that while the interval between Thick and Brooch has increased from 108 to 147 feet, that between Thick and Flying Reed intervening, has increased from 0 to 115 feet.

The condition is not confined to the Carboniferous. Lipold[54] found splitting of coal beds by no means unusual in the Triassic. At one locality, four coal beds were seen. The first and third converge in a westerly direction, the interval decreasing from 72 to 18

[53] J. B. Jukes, "South Staffordshire Coal Field," pp. 36–40.

[54] M. V. Lipold, "Das Kohlengebiet in der nordöstlichen Alpen," *Jahrb. d. k. k. Geol. Reichsanst.*, Band 15, 1865, pp. 85, 99–101, 109.

feet. The variation in position is in the lower or first bed, the place of the third remaining apparently unchanged. The third and fourth, on the contrary, converge toward the east and eventually unite. Bifurcation was observed in other beds and in some cases one or more subdivisions thin out to disappearance. The Cretaceous coals of the Rocky Mountain region show the same feature.

Some of the features so marked in coal beds are equally characteristic of peat accumulations. The description by Morton[55] may be cited as representative; the area has only a few square miles but the conditions are those observed on a grander scale in the great marshes of Holland and Belgium. At one locality Morton saw

Brown and gray estuarine silt	6	0
Upper peat	3	6
Gray estuarine silt	10	0
Lower peat, forest bed	2	0
Boulder clay	2	0

The peat and silt were deposited in depressions; they thin out in approaching the ridges. Sometimes the peat beds unite as they rise on the slopes and occasionally after uniting they become continuous with a surface bed which has never been covered. The lower peat shows many trees *in situ*. The peat about each tree is somewhat higher than that in the intervening spaces. The lower silt contains neither shells nor bones. The upper peat, 1 to 10 feet thick and at times divided by silt, contains no upright stems but there are prostrate stems with twigs and leaves as in a forest. The upper silt is sometimes 20 feet thick, but, there, the upper peat is absent and the silts are continuous. On earlier pages many citations were made, recording irregularities in peat deposits, such as variation in thickness, division or bifurcation of beds, disappearance of "splits" by thinning out, even the phenomenon of the "Flying Reed."

Relations of the Benches in Coal Beds.

The total of coal in the separated splits may be greater or less than that in the undivided bed. The partings in the undivided bed

[55] G. H. Morton, "Further Notes on the Stanton, Ince and Frodsham Marshes," *Proc. Liver. Geol. Soc.*, Vol. VI., 1889, pp. 50–55.

may represent, in time-value, the intervening deposits where the splits are most widely separated—in which case the total thickness of coal may be approximately the same throughout. When a split loses thickness away from the place of union, it may be that subsidence began at some distance from that place and was, so to say, rapid; but where the split thickens, the subsidence was at first extremely slow, permitting accumulation to continue after it had ceased beyond the place of union. Some of the splits increase, others lose in thickness. A study of the benches in each split proves independent history.

One may not regard a coal bed as a single deposit, the result of consecutive deposition, broken only by pretty irruptions of clay or sand. It is the record of accumulation in a given area interrupted by longer or shorter intervals of no accumulation, which are marked by the partings. These intervals in one locality may be synchronous with continued accumulation in another. It is very evident that this accumulation did not begin simultaneously in all portions of the area now marked by a coal horizon and it is equally certain that its termination was not simultaneous throughout. Unquestionably the opening and closing of the work at any given horizon were embraced within a definite period, but one must recognize that only a very small part of the bed may be actually of synchronous origin throughout. Study of the benches of the Pittsburgh coal bed has led the writer to conclude that very little coal accumulated in northern Ohio and much of Pennsylvania until after a notable thickness had accumulated in southern Ohio and in West Virginia. The diminishing importance of the portion below the Bearing-in coal seems to indicate a northward advance of coal-forming conditions. It is equally clear that coal accumulation ceased after the Bearing-in within most of the southern portion, for the Breast is unimportant or absent, whereas it continued long time at the north, as appears from the increasing importance of the Breast in that direction. Changes of similar kind are shown by the Middle Kittanning or Hocking Valley coal of Ohio, which has been studied in detail throughout an area of more than 1,000 square miles, where it has great economic importance. Enough is known to make clear that,

in considering the problem of coal accumulation, one has not to deal with vast areas, since coal never was accumulating at any one time throughout a great basin.

Relation of Coal Beds to Black Shale.

Coal beds vary in character; frequently coal passes gradually into black shale containing laminae of bright or dull coal; occasionally, the passage is almost imperceptible to the eye, the increase in ash causing no marked change in appearance. It is a common observation that, in the Coal Measures, black shale is almost certain to be replaced with coal somewhere. At the Uniontown horizon, in the Monongahela, one finds usually a thinly laminated black shale containing scales and teeth of small fishes and some laminae of coal; but at many localities within its area of several thousands of square miles, this becomes a coal bed which though impure is of local importance. Any coal bed is liable to show this change. The Buck Mountain bed, near the bottom of the Allegheny in the anthracite area, is worthless within a space of many square miles; the Mammoth bed degenerates westwardly and at times is little better than carbonaceous shale. Coal beds as they approach the border of their area are apt to show a greatly increased number of thin partings, usually mud but sometimes sand. Not rarely lenses of sand are intercalated, which may be of considerable extent. Such changes seem to indicate proximity to upland, whence streams came loaded with sediments. They suggest conditions like those which are seen within five or six miles west from New York, where one finds many times a small area of clean peat surrounded by impure material containing layers of mud.

The origin of the black shale is not always clear, but it is a sediment. The carbonaceous matter, in some cases, came in with the sediments as plant fragments, but in others it came rather from animal matter. An illustration of the former condition is found in the work by Scott,[56] who made dredgings in Lakes Ness, Oich and

[56] T. Scott, "The Lochs of the Caledonian Valley," *Scot. Geogr. Mag.*, Vol. VIII., 1892, pp. 94, 95.

Lochy for the Fishery Board of Scotland. In Ness, the dredge was filled with fine mud containing fragments of peaty matter and pieces of partially decayed wood. Some exuviæ of entomostraca were present but no living specimens were observed. The same condition was found in the other lakes where no attempt was made to determine the thickness of the deposit. In these lakes, the water is free from mud and is dark brown, owing to dissolved organic matter from peat. The streams descend from the Highlands, but the region is protected from erosion by a cover of peat, so that only very fine silt is brought down. The brown waters pass out to the sea and the dissolved materials are not precipitated in the lakes.

The presence of vegetable remains along with those of marine animals in many black shales is by no means proof that the water was shallow nor is the association in any sense evidence that the water was deep. The observations by Agassiz[57] have been cited many times in this connection as though they contain the final argument. In reference to dredgings in the Caribbean sea he says, that the contents of some of the trawls would have puzzled a palæontologist; there were deep water forms of crustaceans, annelids, fishes, echinoderms and sponges, mingled with mango and orange leaves, branches of bamboo, nutmegs and land shells, both animal and vegetable forms being in great profusion; so that it might be difficult to decide whether one were dealing with a land or a marine fauna. Such a trawl from a fossil deposit would naturally be explained as representing a shallow estuary surrounded by forests; yet the depth may have been 1,500 fathoms. The large quantity of vegetable matter, thus carried out to sea, seems to have a marked effect in increasing locally the number of marine forms.

Whether or not any palæontologist would have reached the conclusion suggested for him by Agassiz is scarcely open to dispute; the palæontologist's answer to the query would be unequivocal and thoroughly emphatic. Commingling of marine and land elements occurs in shallow as well as in deep portions of the Caribbean, with

[57] A. Agassiz, "Three Cruises of the *Blake*," *Mem. Mus. Comp. Zool.*, Vol. XIV., p. 291.

the distinction that in the latter there are the forms known to be characteristic of deep sea zones only. But no such problem as that imagined by Agassiz presents itself in the Coal Measures—though there are those who believe the contrary. Respecting the marine forms of the Coal Measures time one may assert positively nothing beyond the fact that they are closely related to marine types. There is no evidence to prove that they preferred deep water but there is abundant evidence to show that they had no objection to dwelling in shallow depths; it is sufficiently clear that limestones carrying the typical forms were deposited at many localities where every feature indicates shallow water and close proximity to a shore. This matter has been considered in an earlier part of this work, but it may be well to present additional notes here.

D. White[58] during the summer of 1912 found evidence of presumably shallow water deposition of some Coal Measures limestones in Oklahoma; Udden has described a brecciated marine limestone near Peoria, Illionis. Ashley[59] found near Merom in Indiana 2 to 8 feet of conglomerate, consisting of shale, sandstone and coal pebbles, bedded in calcareous matter and resting on 2 to 4 feet of marine limestone. This conglomerate underlies the great Merom sandstone. A stream flowing over the outcrops entered the sea and dropped its load of coarse material into the unconsolidated upper portion of a limestone containing *Productus* and other marine types. As the conglomerate is coarse, it must have been dropped at once when the stream entered a body of water. The Ames limestone is impure, conglomerate but fossiliferous at a locality in Meigs county of Ohio, as recorded by Condit; on the extreme western border in Muskingum county of the same state the Ames is shaly and coarse grained, showing none of the characteristics observed farther east, but it is fossiliferous; in Carroll, on the northwest border, that limestone on the extreme outcrop is very impure, coarse grained and very like sandstone; at a short distance farther east it is more like limestone but at a mile farther it is earthy and disintegrates on exposure. At these localities, one is very near the original shore, where the water

[58] Letter of October 25, 1912.

[59] G. H. Ashley, "Coal Deposits of Indiana," p. 908.

was shallow and far from clean, but the characteristic fossils persist to the last exposure of the horizon. Bownocker has noted a number of localities in Meigs, Gallia and Lawrence counties of Ohio, all on the western border, where this limestone is impure, argillaceous, ferruginous or sandy, yet the fossils persist. I. C. White found the same conditions along the northern border in Pennsylvania. Hennen[60] reports that in Harrison county of West Virginia, where one approaches the southern limit of the Ames limestone, the rock is an impure limestone, often represented only by dark limy shale but always containing the same marine fossils. The Conemaugh formation has other marine limestones which are brecciated at numerous localities. In some cases the shells are broken as on a shore.

The Occurrence of Cannel.

The cannels and bogheads differ from true coals not merely in structure and composition but also in their mode of occurrence. Cannel is invariably a local deposit, in the extreme sense of the term, though conditions favoring its formation existed more frequently at some horizons than at others. Many of the small isolated basins in Iowa, Missouri and even in Pennsylvania contain only impure cannel, but ordinarily the mineral forms part of a coal bed, the relation being intimate. Invariably, the deposit is saucer-shaped, as though occupying a depression in vegetable matter previously accumulated. White[61] has described a cannel of much commercial importance, though it is confined to only one estate; the mass has a maximum thickness of 12 feet and thins away to nothing in all directions. The changes are exhibited in extensive workings. Platt[62] examined, in Armstrong county of Pennsylvania, three disconnected patches of cannel at the Upper Kittanning horizon. The space between these is occupied by ordinary coal. In each, the cannel is from 0 to 8 feet thick; the bottom bench of the coal bed is bituminous and it is depressed with the thickening cannel, the slope of the

[60] R. V. Hennen, W. Va. Geol. Surv., County reports, 1912, p. 251.
[61] I. C. White, Sec. Geol. Surv. Penn., Rep. *Q*, pp. 213, 232, 258, 259, 268.
[62] W. G. Platt, ibid., Rep. *H5*, p. 176.

upper surface being from 5 to 22 degrees; but the top bench, also bituminous, rests on the horizontal surface of the cannel and is regular throughout, as is also the roof, both showing only the insignificant dip characterizing the region. In Pennsylvania, one rarely finds cannel at the bottom of a coal bed, but that condition occurs occasionally in West Virginia and it is not infrequent in Ohio. Some coals of the Beaver within Ohio and Kentucky have considerable areas of cannel and are spoken of as cannel beds; but even in those the features are the same as in others, excepting as to extent. The story is the same in all areas. Hull has shown that the celebrated Wigan deposit in Lancashire is saucer-shaped; Green found the same condition in the Yorkshire deposits; David, Mackenzie and Wilkinson have recorded many observations showing that the Kerosene shale of New South Wales has similar distribution. The phenomena are familiar in modern swamps.

Distribution of Coal in Relation to the Accompanying Rocks.

The distribution of coal seems to be related in some way to the character of the associated rocks. In the southern and middle anthracite fields, the coal beds are thick at the northeast, where coarse rocks most abound, and become unimportant at the west, where coarse rocks are less abundant. In the Pottsville of those fields, there are thick coals with pebbly rock above and below, though in most cases there is some shale, often very thin, above or below the coal. In the bituminous region, coal beds of the Allegheny and higher formations appear to have accumulated chiefly on the borders of that region—not as continuous bands, but at definite horizons. They thin away and the horizons become indefinite as one approaches the central area, in which fine materials prevail; yet even there, coal was formed in thin irregular deposits at widely separated localities; and these petty accumulations seem to be at or near horizons which are well defined elsewhere. Coal-making conditions did not exist for any considerable period or in any considerable area within the region of fine-grained rocks.

The same relation has been observed in other countries.

Phillips,[63] referring to his studies in Yorkshire, states that toward the southwest the limestones thicken, while sandstones and shales become thin. The sandstones thicken toward the north, while shales thicken toward the west, in which direction certain sandstones and limestones vanish. With those sandstones, the coals also vanish. Where the sandstones thicken and grow numerous, toward the north, in which direction the limestones change from an undivided mass to many members, the coal beds augment in number and in thickness. A similar condition is apparent in eastern Oklahoma.

Coal beds seem to be wholly wanting in the Mississippi limestones of the Appalachian basin. Their absence from this mass, at times more than 2,000 feet thick, including the calcareous shales, can hardly be due to lack of vegetation on the land, for the underlying Pocono or Logan sandstone and shales show definite coal beds from central Pennsylvania to Wythe county of Virginia, a distance of not less than 400 miles; while the sandy division of the Chester, equivalent to the highest part of the Mississippian, contains thin coal beds at many places west from the old Cincinnatian land. The writer has not been able to make sufficient study of conditions elsewhere to justify him in offering a generalization; but in the Appalachian basin, every observation indicates that conditions favoring deposition of marine limestone or of fine detritus in extended areas are not favorable to the accumulation of coal beds.

Macroscopical Structure of Coal in Beds.

The several benches of a coal bed may show marked differences aside from those already mentioned. The coal from one may be impure, containing large percentage of ash or sulphur; that from another may be hard, breaking into more or less regular blocks; that from a third may be brilliant, tender; that from a fourth may be prismatic, the rude prisms or columns being readily separable with the fingers; that from a fifth may be a solid coal, yet not hard enough to bear rough handling; while any one of the five benches may show saucer-shaped inclusions of cannel. These variations are shown in

[63] J. Phillips, "A Treatise on Geology," new ed., London, 1852, Vol. I., p. 190.

the Pittsburgh coal bed and are illustrative of those shown by nearly all beds. They are associated with equally marked chemical differences, which will be considered on a later page.

The coal in all benches has a laminated structure, due perhaps in some cases to pressure but in others to some other cause. The writer has traced laminæ, which tapered to nothing in each direction along an entry; whether or not this is characteristic, he cannot say. Any one who has attempted to determine this matter in a coal mine must have recognized that the intense application required should be devoted to something more important. H. D. Rogers concluded that in pursuing any brilliant layer, not more than one fourth of an inch thick, one may observe that its superficial extent is too great to permit the supposition that it had been derived from the flattened trunk or limb of any arborescent plant. It is certain, however, that pressure cannot account for the alternation of brilliant or glance laminæ with those of dull or matt coal, which one finds almost invariably. Usually these layers are very thin, but in many instances they are several inches thick. Sometimes this lamination seems to be due to the presence of mineral charcoal, which covers every surface obtained by splitting, but at others the charcoal is clearly without influence, for it lies in all directions. This mineral charcoal is a common constituent of all the fuels from anthracite to peat, but it is not an essential constituent, for layers of glance several inches thick have been found without it and Orton[64] has described a coal bed of workable thickness which shows no trace of it.

Fragments of plants, sometimes large, occur in coal. Occasionally they have been converted into fusain but more frequently they appear as glance coal,—though even these occasionally enclose more or less of the charcoal. Ordinarily they are flattened, the interior having disappeared while the cortex remained to be converted into glance. At times, they are merely impressions on the apparently structureless mass of coal, recalling the conditions observed in many peat deposits, where the great bulk of vegetable material has been changed into the flocky ulmic mass, while enclosed stems of trees,

[64] E. Orton, "Mines of Muskingum and Licking Counties," Geol. Surv. Ohio, Vol. V., 1884, p. 881.

changing more slowly, are still recognizable. These stems are found in coals of all types and they are associated very commonly with leaves.

Lesquereux[65] asserted that *Stigmaria* occurs as frequently in American as in European coals. In Greenup county of Kentucky, he saw a cannel, 4 feet thick, containing such abundance of *Flabellaria* and *Stigmaria* that he believed the coal to be composed of those plants. In another, he found great numbers of *Stigmaria* and beautiful impressions of *Lepidodendron*. Coal beds I. and XII. in western Kentucky are composed in places of flattened *Stigmaria, Calamites* and *Sigillaria* with, in I., *Lepidodendron*. The Breckenridge deposit is rich in fine impressions. Long ago, E. B. Andrews, in writing of the Ohio and Kentucky cannels, said that *Stigmaria* seemed to revel in the ooze which became cannel. Orton[66] says that the upper or bituminous portion of the Upper Mercer coal bed contains "the most beautiful specimens of *Stigmaria;* nearly every mine car contains what would be a prize in a geological museum." These retain their lateral appendages. Many incidental, possibly accidental references are found in other geological reports, but they give no details. At the same time, they suffice to show that remains of trees are recognizable in the coal of very many beds and that *Stigmaria* is not confined to the lower part of the deposit, but occurs in all portions in bituminous as well as in cannel.

Dawson[67] examined carefully every coal bed exposed in the long South Joggins section. Many deposits of inferior coal in Divisions 3 and 4 are composed of recognizable leaves and stems and there are beds of clean bright coal containing *Sigillaria, Cordaites* and other forms. The stems are almost invariably prostrate, but in one coal bed he saw a coaly stump and an irregular layer of mineral charcoal, "arising apparently from decay of similar stumps." In another bed, composed of prostrate *Sigillaria* with *Cordaites*, etc., he found a

[65] L. Lesquereux, "Geology of Pennsylvania," 1858, Vol. II., p. 841; Third Rep. Geol. Surv. Ky., 1857, pp. 529, 532, 548; Fourth Rep., ibid., 1861, pp. 342, 349, 368, 379, 405, 412.

[66] E. Orton, Jr., Ohio Geol. Surv., Vol. V., 1884, p. 850.

[67] J. W. Dawson, "Acadian Geology," 2d ed., pp. 159, 162, 168, 171, 173, 174, 190, 438.

stump as mineral charcoal, while, in another, a trunk was seen, reduced to little more than coaly fragments, surrounded by a broken, partly crushed cylinder of bark. His study convinced him that the bark of *Sigillaria* and allied plants gave the bright coal, while wood and bast tissues yield mineral charcoal, the dull coal coming from herbaceous plants and mold.

Goeppert[68] found in the coal itself not only the plants which characterize the accompanying shale, but also many other species, especially of *Sigillaria.* The coal contains, in areas studied by him, *Stigmaria, Sigillaria, Caulopteris, Calamites* and other types forming stratified beds, 30 to 40 feet thick. Of the stems, only the rind remains and that is pressed flat. Where the chemical change was long continued, the features of the rind disappeared and the coal became structureless; but he often saw structureless coal pass into that with well-defined structure. At some localities the coal is composed of Araucarian stems and *Stigmaria,* while at others *Lepidodendron* is so abundant that one can hardly find a piece not containing that plant.

Grand'Eury[69] says that *Stigmaria* is very abundant in the coal of Rive-de-Gier; that *Cordaites* forms the greatest part of the coal in mines near Saint-Chaumond and in those of the Chazotte; it seems to be almost the only form in the coal of Tartaras, but is associated with ferns at Peron Midi and at Gandillon. At some places near Saint-Etienne, *Sigillaria* makes up practically whole beds of coal. Conditions are similar in other parts of Europe. He cites von Ettinghausen, who states that, at Radnitz, the coal-forming plants are *Sigillaria* and *Stigmaria,* with *Lepidodendron* and *Calamites,* but the latter two as well as the ferns are unimportant. Grand'Eury found similar conditions at Eschweiler, Wurm, Essen and Saarbruck; Geinitz called the Plauen deposit, *Calamites* coal. But Grand'Eury emphasizes the fact that a coal bed has not been formed by any single kind of plant. He remarks that occasional specimens of stems are found, converted into carbonized wood, showing the

[68] H. R. Goeppert, "Prize Essay," 1848, pp. 69, 70, 72–75, 276, 277, Pl., Fig. XVI.

[69] C. Grand'Eury, "Flore carbonifère du Département de la Loire et du Centre de la France," Paris, 1877, pp. 153, 168, 212, 213, 259, 396–398.

cortex and the intra-cortical fusain, which is finer than that from the wood.

Fayol[70] learned to distinguish coal made from *Calamodendron, Cordaites* or ferns as readily as he could distinguish a piece of beech from one of fir. He recognized these types first in isolated laminæ, but afterwards in brilliant laminæ occurring in the thickest and purest parts of the Grande Couche. He saw tree trunks in Commentry, some buried in the lower benches of the coal and others passing from the coal into the overlying shale. One fourth of one percent of the trees in the coal are vertical, an equal proportion are inclined and the others are prostrate. Few trunks in coal are cylindrical; where such stems occur, one can prove usually that one of the extremities is in sandstone.

David,[71] in describing deposits of Kerosene shale, reports that in one mine at the end of Megalong ridge, the shale contains erect stems of *Vertebraria;* in another, prostrate stems; in a third are flattened stems or "barky casings of plants turned into bituminous coal, over four inches in width." David saw many vertical and prostrate stems of *Vertebraria* in the Shale at a locality in Cook county. Wilkinson saw at Joadja creek impressions of *Vertebraria* lying horizontally in the Kerosene shale as well as numerous vertical stems of the same plant, whose lustrous, bright substance is in striking contrast to the dull luster of the enclosing shale. Nathorst found stems of *Bothrodendron* in the Devonian coal of Bear island and stems are present in many brown coal deposits as well as in the peats of modern bogs.

Foreign Bodies in Coal.

The presence of tree stems in coal is normal; but the coal often contains what may be regarded as foreign bodies.

Nodules of calcareous clay-iron stone are familiar objects in coal beds as well as in the Coal Measures shales. They are from mere specks to balls a foot or more in diameter. Occasionally they

[70] H. Fayol, "Études," etc., pp. 135, 196, 198, 206, 207.

[71] T. W. E. David, Dept. Mines New South Wales, Rep. for 1890, 221–224; C. S. Wilkinson, ibid., p. 208.

are rudely spherical but for the most part the shale is irregularly oval and occasionally even plate-like. When enclosed in coal beds, the laminæ are displaced about them as though the final compression had taken place after formation of the nodule; and this feature is as characteristic of coals which have not been distorted as of those which have been folded. The nodules are often fossiliferous, containing marine shells at times but land forms and plants at others—as those obtained at Mazon creek in Illinois, in which are remains of many animals as well as plants, all marvelously well preserved. Such nodules have been found in the Devonian, for Nathorst[72] obtained some from shales of that age in Spitzbergen; *Lepidodendron* and apparently *Bothrodendron* were recognized in several of them, while others contain remains of fishes.

More than 80 years ago, calcareous nodules more or less ferruginous, occurring in the roof and coal of a thin bed in the Lancashire coal field, attracted Binney's attention and were made the subject of a memoir by Hooker and Binney. Since that time, such nodules have been discovered in many lands and have been investigated by students in Europe. In this summary, reference is made only to some of the later publications.[73]

Coal balls were supposed for a long time to be confined, in England, to a single horizon, the thin Lancashire coal bed known as the Mountain Upper Foot. This, in the Lower Coal Measures, is at a variable distance above the Ganister coal bed, one of the most per-

[72] A. G. Nathorst, "Zur palaeozoischen Flora der arktisches Zone," *Hand. K. Svens. Veten-Akad.*, Band 26, No. 4, 1904, pp. 11, 13.

[73] D. Stur, "Ueber die in Flötzen reiner Steinkohle enthaltenen Stein-Rundmassen und Torf-Sphaerosiderite," *Jahrb. d. k. k. Geol. Reichsanst.*, Vol. XXXV., 1885, pp. 628 et seq.; A. Strahan, "On the Passage of a Seam of Coal Into a Seam of Dolomite," *Quart. Journ. Geol. Soc.*, Vol. LVII., 1901, pp. 297–304; H. B. Stocks, "On the Origin of Certain Concretions in the Lower Coal Measures," ibid., Vol. LVIII., 1902, pp. 46–58; M. C. Stopes and D. M. S. Watson, "On the Present Distribution and Origin of the Calcareous Concretions in Coal Seams, known as 'Coal Balls,'" *Phil. Trans. Roy. Soc.*, Ser. *B*, Vol. 200, 1908, pp. 167–208; W. Gothan und O. Hörich, "Ueber Analoga der Torfdolomite (Coal Balls) des Carbons in der rheinische Braunkohle," *Jahrb. k. preuss. Landesanst.*, Band XXXI., Teil II., 1910, pp. 38–44; C. Barrois, "Étude des strates marines du terrain houiller du Nord," 1re Partie, 1912, pp. 4, 9, 38, 62.

sistent members of the column. The Ganister, when separated by several yards from the upper Foot, contains no balls; but when the parting is only a few inches, the balls are in both beds. There is no regularity in the distribution. The Hard coal bed, near Halifax in Yorkshire and belonging apparently at the same horizon, also contains similar balls. These concretions have a slickensided surface and the coal laminæ curve around them; occasionally a faulted specimen is found. In size they vary from an inch to a foot or even more—one, near Shore, weighs 2 tons and replaces the coal from roof to floor. These balls in the coal contain plant remains in condition of remarkable preservation.

The roof shale of this coal bed carries abundant remains of marine animals along with much fragmentary plant material. "Bullions," "baumpots" or "Goniatite nodules" occur in this shale and are as characteristic of it as the coal balls are of the coal. These roof balls enclose shells with which there are often bits of plants, rarely well preserved but at times admitting of generic determination. Sphærosiderites, answering to the English roof balls or bullions, have been found within the Nord (France) basin in marine shales, sometimes resting on thin coals. They, like the English balls, contain *Goniatites, Productus* and other forms; but Barrois does not note the presence of similar concretions in the coal.

Sphaerosiderites were obtained at collieries in the Ostrau coal field from the roof shale of the Heinrichs and Coaks coal beds; in each case the shale is marine. The balls from the higher shale are occasionally fossiliferous but those from the roof of the lower bed seem to be without fossils. The lower part of this shale, however, is crowded with small balls of pyrite, many of which are fossiliferous, while many shells in this portion have been replaced with pyrite. The balls, for the most part, are small, very irregular in form and often are polished, so that they might easily be mistaken for erratics. Sometimes several are united but ordinarily they are separate and are scattered throughout the shale. They are encrusted with powdery matter, one to two millimeters thick, which is removed readily by washing. When exposed to the weather, their concretionary structure soon becomes apparent.

The Coaks bed contains great numbers of coal balls or plant-sphaerosiderites; Stur obtained several hundreds in a large block of coal shipped to him from the mine. These are especially abundant in the upper bench and on the west side of the area, where the roof balls also are most numerous. The remains of plants in the coal balls are always well-preserved but those in the roof balls are in bad condition.

The roof balls, according to Stopes and Watson, have from 4 to 6 per cent. of clay, whereas the coal balls have often no more than a trace. Stur has given two analyses of those from the roof, which are quite dissimilar:

Carbonate of calcium	61.43	29.01
Carbonate of magnesium	2.86	4.33
Carbonate of iron	16.13	25.09
Carbonate of manganese	1.73	——
Sulphide of iron	——	6.45
Clay	2.49	2.22
Insoluble matter	13.03	30.20
Water and loss	2.33	2.70

The coal balls show extreme variations in some constituents. According to Stopes and Watson, those from Bacup are chiefly dolomite; whereas several of those from Shore show very little magnesia, and only 2 of the 5 specimens analyzed have more than 5 per cent. of carbonate of magnesia. Stocks analyzed two from Yorkshire localities, which gave

Carbonate of calcium	64	82
Carbonate of magnesium	2	0.75
Sulphide of iron	21	12

with small per cent. of sulphate of calcium, silica, clay and organic matter. Sometimes the nodules contain pieces of fossilized wood which are large enough for study. They also show much variation, 4 specimens giving

Carbonate of calcium	86	24	87	49
Carbonate of magnesium	4	2	3	6
Sulphate of calcium		14	1	9
Sulphide of iron		49	5	24

with other constituents in small proportion; the fossilized wood like the mass of the concretion is composed chiefly of carbonate of calcium and sulphide of iron. The analysis of Stur's specimen differs somewhat; it is

Carbonate of calcium	56.52
Carbonate of magnesium	10.02
Carbonate of iron	15.60
Clay	0.89
Insoluble matter	0.17
Organic matter, water, loss	16.80

but, like the other analyses, it shows the great freedom from clay and silica, which are so important in roof balls. This difference led Stur to distinguish the latter as clay-sphaerosiderites.

Except at the Bacup locality, dolomite is not the important constituent of the coal ball. Strahan's notes respecting the Wiral colliery in Cheshire seem to have some bearing on this matter. The coal there was 4 feet thick and of good quality where opened; but within a short distance bands of stone, 1 to 10 inches thick, appeared, some of them consisting of spherical pellets. Within 250 yards, the coal was replaced with this rock, but the roof and floor remained unchanged, save that the former had become reddened—this change, however, being unrelated apparently to that in the coal. The rock is black and hard, but weathers gray; the structure is pisolitic and the concretions are sometimes united, at others independent and separated by coaly matter. They consist of dolomite with some coaly material, iron, silica and clay. Some fragments are composed of small masses or irregular crystalline layers, separated by fine mud containing quartz and flakes of mica; while others, consisting partly of woody tissue filled with dolomite, may be regarded as wood fragments, impregnated with and cemented by dolomite. When this dolomite has been removed by acid, a copious residue of carbonized fibers is obtained.

These balls or sphaerosiderites are concretions formed in the coal and shale after the deposits had been made but before consolidation. The laminæ of coal and shale curve around them and some of the concretions were broken during the later compression.

Green[74] in describing the Yorkshire roof balls says that the *Goniatites, Aviculopecten* and other shells enclosed are not flattened as are those in the shales. The plant material in the coal balls is in wholly uncompressed condition, so that the minutest details of structure can be recognized—as one may see by consulting Williamson's memoirs in the *Transactions of the Royal Society*. Stur found the stems of plants not only uncompressed but also, in some cases, not wholly decayed, so that the concretions were formed before the chemical change had been completed. Stopes and Watson were convinced that they had traced a stem continuously from one coal ball into another; Wild says that the Lancashire "bullions," composed of fossil wood, occasionally show rootlets working their way through the decaying wood, separating the fibers which now surround them. But vegetable fragments in roof balls are different; as Stur remarks, they are coaled and evidently much changed; they tell little of relations and less of structure.

But coal balls are not confined to the Coal Measures. Gothan having noted that the localities, where the balls had been obtained, were all within paralic basins set himself to discover them under other conditions. Petrified stems are common in Tertiary beds, where, as deposition centers in brown coal, they have given opportunity for concentration. Such silicified or at times pyritized stems occur frequently in the Halle brown coal and in the Rhenish brown coal one finds the well-known oolite wood. But these are not wholly analogous to coal balls, which are bits of petrified peat, penetrated at times by roots of vegetation growing above. In searching the survey collections at Berlin, Gothan found a piece of brown coal from the Donatus mine near Cologne, which contained spherules of carbonate of iron, the same as the material of the oolite wood. Deposition had not been confined to the wood but had reached into the actual peat. Specimens were procured from Flügel, who had mapped the area, and they proved to be part of the bed, replaced with material like that of the plant-balls described by Stur. Gothan suggests the name of Torf-Dolomite. Microscopic examination by Hörich showed the close resemblance between these forms and the coal balls. As a

[74] A. H. Green, "The Geology of the Yorkshire Coal Field," p. 108.

rule, however, the plant remains are less well preserved than in the coal balls; they are so disintegrated that in many cases they are not identifiable. Roots are best preserved, probably because they entered when the surrounding mass had already become peat. They show no trace whatever of compression. Some fragments of stems have great lacunæ, indicating that they are of plants belonging to a moist habitat. The great variety in the plants suggests that the deposit is a typical Waldtorf, which accords with the belief that the brown coals were deposited as Waldmoors.

This conclusion is very similar to that reached by Stopes and Watson, who recognize a swamp vegetation in the coal balls, as, indeed, Stur had done long before. Stur had noted the difference in condition of the vegetable material in the two types of balls, and this difference is emphasized by Stopes and Watson. Scott had observed that the roof-ball flora, though of Lower Coal Measures age, has no slight resemblance to that of the Permian, and those authors think that it is comparable to an upland flora, so that it may be more characteristic of the widespread vegetation than is that of the coal balls.

Dolomite, calcite and carbonate of iron are not the only minerals replacing plant material in concretionary fashion. E. B. Andrews and Lesquereux found wood in coal wholly replaced with sulphide of iron, the form being uncompressed; but no microscopic study was made to ascertain whether or not any trace of structure remained. The Grand'Croix flints are of the same type as the coal balls and they yielded interesting results to Renault, who recognized that they are petrified peat. Near Salem in Oregon there are fossil stems, which show all gradations between lignite and silica within a few feet.

The source of the material forming the balls has been subject for speculation. Balls from the more celebrated localities are in coal beds with marine deposits as the roof. Binney thought the shells provided the material, but objection was made that the shells are not dolomite and that one should look to sea-water as the source. As the roof shales in the Coal Measures localities are marine, sea-water must have covered them all alike; yet in Lancashire, the balls are dolomite at Bacup, whereas at Shore only one specimen showed

as much dolomite as calcite while in three others dolomite is absent or insignificant. Dolomite is unimportant in the Yorkshire balls, but it is in large proportion in Stur's specimen, while it is shown in small proportion by the roof balls of the same area. It would appear that sea-water can hardly be regarded as the source, in view of the marked variations found within short distances. And this suggestion is strengthened by the fact that Gothan's Torf-dolomite closely resembles in composition the coal balls described by Stur.

It may be preferable to seek the source in the materials themselves, the inorganic matter forming the shales and the ash of the coals. Carbonate of magnesium is found in most of the coals as well as in peats and it is often an important constituent of wood ash. The varying proportion in the balls may indicate merely a varying proportion in the shales, depending on the nature of the rock whence they were derived. And this seems to be reasonable, when one considers the composition of limestones. McCreath[75] made many analyses for the Pennsylvania survey, which illustrate the conditions. The Vanport limestone of the Allegheny formation is of marine origin throughout and is one of the widely extended deposits. Carbonate of magnesium rarely exceeds 2 per cent. and very often is less than 1 per cent.; but on the northern border, where it extends into old valleys and is mingled with land material, the percentage increases, attaining 6.65 at one locality. A similar change appears in the Ames limestone. In Harrison county of West Virginia, that limestone is approaching its southern limit as a marine deposit. It contains in its upper division 25 per cent. of alumina and in the lower, 18 per cent. of silica. The influx of land material is very marked, though the marine fossils persist in great numbers; the carbonate of calcium varies from 40 to 48 per cent. and carbonate of magnesium from 15 to 21 per cent.[76] McCreath's analyses of Monongahela and other limestones, which from their relations must be regarded as non-marine, show that in some cases they are markedly dolomitic and with few exceptions they have a

[75] A. S. McCreath, Sec. Geol. Surv. Penn., Rep. *MM*, 1879, pp. 281–362; Rep. *M3*, 1881, pp. 79–94.

[76] B. W. Hite, in West Va. Geol. Surv., County Reps., 1912, p. 251.

large percentage of insoluble residue. Lesley's[77] study of the elaborate series of analyses, showing composition of the 115 layers of limestone exposed opposite Harrisburg, led him to conclude that in this exposure two types of deposits alternate; one is of limestone, with 2 to 3 per cent. of carbonate of magnesium and 1 to 2 per cent. of insoluble matter; the other, a dolomitic limestone, with 26 to 35 per cent. of carbonate of magnesium and the insoluble matter is from 7 to 15 per cent. The large percentage of silicate of aluminum is always in the dolomitic beds. The layers analyzed are from a few inches to 8 feet thick, are distinctly separate and the extreme variations of composition are often in direct contact. One who reads carefully the whole of Lesley's discussion is compelled to recognize that the differences are orignal, not secondary, that they are due to conditions in the drainage area, not to change in composition of the water in which they were deposited.

The replacement described by Strahan may be due to mineral springs as are the flints of Grand'Croix.

Remains of animals may be regarded as foreign bodies. Cannel often contains abundance of such remains. In such localities, on both sides of the Atlantic, it has been a rich mine for the palæontologist. Marine shells have been found in ordinary coal. The Harlem coal bed, underlying the Ames limestone, has marine forms in its topmost layer at a locality in Ohio as well as at one in West Virginia and Raymond found a marine shell in the Kittanning coal at a locality in Ohio. Remains of higher animals occur in coals of later age. Anker[78] examined a brown coal of Molasse age in Styria, which so closely resembles black coal that is distinguishable only by its geological position and its occasional woody structure. Bones are present in 3 layers, where they are very numerous, though fragmentary. A jawbone, retaining the teeth, was recognized as belonging to *Hyena*. Bones of mammals occur frequently in modern swamps.

[77] J. P. Lesley, Rep. *MM*, pp. 360, 361.

[78] Anker, "The Occurrence of Bones of Animals in a Coal Mine in Styria," *Proc. Geol. Soc. London*, Vol. I., 1834, p. 467.

Fragments of rock are the foreign bodies which are the most perplexing. The earliest recorded observation seems to be that by Phillips in 1865, followed by that of Noeggerath in 1862, both of which have been cited by Stur. Roemer[79] soon afterward described 3 small fragments from a coal bed in Upper Silesia; they were of crystalline rock, unlike anything known in Silesia. E. B. Andrews in 1870 announced the discovery of a waterworn quartzite fragment in the coal at Zaleski, Ohio, half embedded in the coal. Newberry in 1874 saw a fragment of talcose slate in the parting of Coal No. 1 at Mineral Ridge, Ohio, which he thought might have come from the Canadian Highlands; somewhat later he found a rounded quartzite fragment in the Block coal, resembling a Huronian rock in Canada. Stevenson in 1877 reported the discovery of a waterworn limestone bowlder embedded in the Sewickley coal of Fayette county, Pennsylvania. It was about 2 feet in diameter and extended above as well as below the coal. He believed that it had not been deposited prior to the coal, for that was splashed as though the fragment had fallen into soft material. Similar notices appeared from time to time but in all cases they were merely casual.

Stur[80] in 1885 gave a summary statement of knowledge respecting such occurrences. He notes the discovery by Roemer in 1883 of a mass weighing 55 kilogrammes, granite such as is unknown in the region. He adds instances coming under his own observation in several Austrian coal fields, but the notes refer to somewhat widely separated localities and the fragments are of small size. Radcliffe[81] described 6 bowlders from Dukenfield, England, embedded partly in the coal and partly in the overlying shale. The portion within the coal had a coaly crust but no such crust appears on the part within the shale. All are of quartzite and the weight was 5 to 166 pounds. One specimen was on edge. W. B. Dawkins

[79] F. Roemer, "Ueber das Vorkommen von Gneiss- und Granulit-Geschieben in einem Steinkohlenflotze oberschlesiens," *Zeitsch. Deutsch. Geol. Gesell.*, Band XVI., 1864, pp. 615–617.

[80] D. Stur, "Ueber die in Flötzen reiner Steinkohle enthaltenen Stein-Rundmassen," etc., pp. 613–647.

[81] J. Radcliffe, "On Grooves and Quartzite Boulders in the Roger Mine of Dukenfield," *Quart. Journ. Geol. Soc.*, Vol. XLIII., 1887, pp. 601, 603, 604.

remarked in the discussion that such fragments occur frequently in Lancashire and that all are of quartzite; Bonney made the broader statement that they are of common occurrence in coal. In the same volume, J. Spencer referred to a granite fragment, weighing 6 pounds, which had been found in the Ganister coal bed and he adds that the surrounding coal was undisturbed. He remarked that bowlders had been found at many localities, that they were always isolated and that they had come from a distance. Gresley in 1890 reported that a well-rounded quartztite bowlder, 11 by 8 inches, had been taken from underclay at 1 foot below the Mammoth coal bed near Mr. Carmel, Pennsylvania.

Orton[82] says that prior to 1892 the Ohio bowlders had come from the Middle Kittanning coal bed at Zaleski. The first was discovered by Andrews in 1870, but many were discovered afterwards, there being at times scores in a single room. The largest weighs 400 pounds and is in the State museum at Columbus. A new horizon was made by finding a quartz bowlder, weighing 10 pounds and 10 ounces, at Mineral Ridge. It was in undisturbed coal at 2 feet below the roof and it was covered with a closely adhering, slickensided crust of coal. Stainier[83] gathered observations made by himself and others in the Belgian fields. Some of the fragments are rounded and smooth, evidently rolled pebbles, while others are irregular in form like concretions, but composed of sedimentary material and so are to be regarded as foreign bodies. Pebbles of the former type were obtained at 8 localities. They are not rare in La Rochelle colliery of Charleroi at the 500-meter level but they are wanting at the 250-meter level. The bed yields an impure coal and earthy partings are numerous where the pebbles occur. The largest is oval, 14 by 8 by 8 centimeters. Schmitz obtained rounded fragments from localities in the Charleroi and Centre basins, and Lohest found them in the Liége basin. The largest specimens weigh 20 and 25 kilogrammes. It is noteworthy that the Belgian fragments are

[82] E. Orton, "On the Occurrence of a Quartz Bowlder in the Sharon Coal of Northeastern Ohio," *Amer. Journ. Sci.*, III., Vol. XLIV., 1892, p. 62.

[83] X. Stainier, "On the Pebbles Found in Belgian Coal Seams," *Trans. Manchester Geol. Soc.*, Vol. XXIV., 1896, pp. 1–19.

of sedimentary origin; some resemble Carboniferous rocks and all are in coaly material. These records seem to suggest that pebbles are not abundant in coal and that they are even of comparatively rare occurrence—the instances noted by Orton and Stainier are not exceptions, as they are examples of extreme localization.

Barrois[84] undertook systematic study of the matter in a definite area and presented the results in an elaborate memoir, of which only the merest synopsis can be given here. Most of the fragments were obtained during a four months' exploration of the Vein-du-Nord, a double bed, showing great constancy in the explored area, which is 7 kilometers long. The upper bench, 0.25 meter thick, has 14 per cent. of volatile and only 2 per cent. of ash, while the lower bench, 0.35 meter thick, has 17.2 per cent. of volatile and 10 per cent. of ash. The rock fragments are coated with soft sooty coal, often pyritous, and the lamination is more or less distorted about them. In all, 295 specimens were secured, of which 86 per cent. were derived from Coal Measures rocks, a few from Cambro-Silurian deposits and nearly 11 per cent. from the distant Archæan. The largest fragment weighs about 120 kilogrammes or approximately 280 pounds. The great preponderance of fragments from the Coal Measures shows that outcrops of those rocks were not far away, so that at the time of the Assise d'Andenne—the Lower Coal Measures—the beds of that epoch were no longer mere muds and sands, but consolidated shales and sandstones; some fragments show even the jointing of contraction. Many are thoroughly water-worn, others are angular, and both types are mingled indiscriminately. In some other coal beds of this region, fragments have been found in the mur, coated with clay which is marked with lacework of *Stigmaria* rootlets.

Fragments were found in all portions of the bed, from bottom to top, but the upper bench yielded 50 times as many as the lower. The number averages only one to each 100 square meters of area, but the distribution is irregular and they occur, as it were, in nests. The more abundant occurrences are associated with contractions of

[84] C. Barrois, "Étude de galets trouvés dans le charbon d'Aniche, Nord," *Ann. Soc. Géol. du Nord*, Vol. XXXVI., 1907, pp. 248–330.

the bed, where the roof or the underclay replaces more or less of the coal. Rolls in the roof usually consist of material differing in character and arrangement from the overlying shale, as though deposited in channels of streamlets made after formation of the coal. The underclay swellings may have been laid down in drowned channels made anterior to formation of the coal and occupied after that formation had been begun. Variation in direction of channels during accumulation of the beds might account for distribution of the fragments but the existence of such waterways within this area is problematical and it is well to seek another explanation.

Phillips's hypothesis that the fragments were transported by trees, uprooted from banks of streams, has found favor with allochthonists and autochthonists alike; but there are serious objections to it. The weight of some fragments, upwards of 100 kilogrammes, is too great to admit of transportation by *Stigmaria,* while the presence of blocks of mud would suggest that hollow trees had shared in the work. In any event, there would always remain the remarkable purity of the coal, so difficult to explain in view of the great amount of inorganic material known to be transported by floating trees. There seem to be insuperable difficulties in the way of a conception that the presence of fragments is due to the agency of trees growing outside of the area in which coal was forming. Objection to the hypothesis of transport by floating ice is equally serious. Beyond doubt there were widespread changes in climatic conditions toward the close of the Palæozoic, but attempts to reconcile the tropical character of the Nord-basin flora with a cold climate have not been successful. The markings on the fragments do not resemble those made by glacial action.

The presence of fragments in the mur is proof that they were brought in prior to formation of the coal, when streams were distributing the detritus which became the mur. *Stigmariæ* became rooted in that and enlaced the fragments, which some day they were to transfer to the coal. The fall of trees, overturned in the marsh by age or wind, tore portions of the mur from below; fragments, there encased, came gradually to the surface of the coal; at times a stump fell into a stream and its load would be deposited in the

channel. This hypothesis explains local abundance of fragments by two factors; their previous existence in the mur and the fragility of the mur itself; so that they would form in succession part of the mur and part of the coal. The purity of the coal eliminates, during formation of the bed, the agency of convoys of allochthonous trees loaded with extraneous debris.

The condition is not peculiar to the Coal Measures. It is found in coal formations of other ages. Hutton[85] found in the Upper Cretaceous of southern New Zealand a sandstone mass, 8 feet by 3, resting on the coal, which convinced him "that there can be no doubt that this boulder has been floated to its present position among the roots of a tree and that therefore the coal beds are formed partly from driftwood." He states the Tertiary brown coals in several fields contain pebbles of white quartz; these beds, according to Hector, rest on fireclay. Jack[86] found pebbles in coals of Upper Cretaceous age in Queensland.

The presence of rock fragments in coal has always been perplexing to allochthonists and autochthonists alike, though each seems to be certain that in some way or another they afford an important argument in favor of his doctrine. They are certainly transported materials; some were brought from rocks far away and most of them are distinctly waterworn. If all were small, any geologist could conceive of an explanation, which would be satisfactory to himself, as refutation might be difficult; but when one has to deal with masses of several hundred pounds, such as the Ohio blocks, transported several hundreds of miles, the problem becomes serious.

Some writers have been inclined to regard ice as the transporting agent; but the character of the Coal Measures vegetation appears to be conclusive against the supposition that intense cold prevailed during any part of the year at any locality whence the fragments have been reported. It is very true that sharply contrasted climates may exist only a few miles apart, as in southern California, but that

[85] F. Hutton, "Report on Geology and Gold Fields of Otago," Dunedin, 1875, pp. 101, 103.

[86] R. L. Jack, "Geology and Palæontology of Queensland and New Guinea," London, 1892, pp. 536, 538.

condition requires topographical features which did not exist. The whole Coal Measures area of Ohio was a low plain; the nearest highlands were in Canada, hundreds of miles toward the north, and the Appalachians, hundreds of miles away toward the east. The agency of ice must be set aside as in the highest degree improbable.

The majority of authors have supposed that uprooted trees floated away carrying the masses entangled in their roots; but the difficulties involved in this conception appear to be insuperable. There can be no doubt that trees do seize such blocks and that under proper conditions they could transport them. Any one, who has seen the manner in which the white birch of the White Mountains enwraps its roots about blocks of stone weighing half a ton or more, recognizes that trees do seize large fragments. But that is not the question. The observer is confronted at once with the problem of conveying that tree and its load to deep water, sea or lake, where the great tree, 75 or more feet high, may float in vertical position, almost wholly submerged. Trees grow on the land, where alone the fragments can be obtained. The transfer cannot be made by torrents, as tree and load would be deposited at the first rapids. A débâcle, like that of Martigny or Johnstown, cannot be conceived of as the agent, since a topography would be required such as did not exist near any of the extensive coal fields whence large fragments have been reported. Even had it existed, the terrific collisions, as the flood dashed through narrow gorges and spread out in wider portions of the valley, would have dislodged the fragments long before reaching the open water. The bowlders cannot be relics of floating islands, such as those of the Orinoco, Amazon or Congo, since the origin of those islands forbids the suggestion.[87] Nor is there any reason to suppose that trees growing on the seashore could become the transporting agents, for, even though river-worn or wave-worn fragments were abundant on the shore, the difficulty of transferring the tree to deep water would still remain. If the trees grew on the river banks, along the lower reaches of a great stream, and were undercut, they would be stranded at the first bar to become

[87] "Formation of Coal Beds," these PROCEEDINGS, Vol. L., 1911, pp. 551, 553, 554.

snags or towheads, which even the greatest flood possible on such a river could not dislodge, as conditions along the Mississippi abundantly show. It is impossible to conceive of any means whereby a tree capable of carrying such a load could be floated away to deep water, unless it grew on the wall of a fiord—where it could not secure the water-worn fragments.

The assumption that shales, sandstones and conglomerates were deposited necessarily in deep water or in a permanent body of water must be regarded as unsupported by any positive evidence. The writer, during a tedious search through the literature, has not found that authors think that the proposition needs evidence; it seems to be accepted as axiomatic. But evidence to refute the doctrine abounds in the Tertiary and Quaternary and, in so far as the Appalachian Coal Measures are concerned, the facts seem to indicate that they are flood-plain deposits and reworked alluvial fans. This condition may afford a clue to explanation for some of the occurrences. Rivers, torrential in their upper reaches, flowed across the plain. Rolled fragments of varying size were pushed along the beds. Pebbles of quartz,[88] 5 inches in diameter, have been found in the Sharon of southern Ohio at not less than 300 miles from their source. During a great flood, if the stream were dammed temporarily, the water would sweep over the "bottoms" or break across the necks of curves; a new channel would be cut, the old channel above for a short distance would be scoured and its sand and pebbles would be strewn on the river-plain. This happens only too often along the Mississippi, as has been shown on preceding pages. In such a rush of water, a block of 400 pounds would be gathered up in the mass as readily as though it were a pebble; but gravity would act promptly and the coarse fragments in the load would be left scattered on the surface while the finer materials would go far beyond. Succeeding floods would cover the sands and gravels as well as the larger fragments with finer materials in which the larger river-worn masses would be widely separated, for the most part, though here and there they would be grouped in smaller areas. One finds this

[88] E. B. Andrews, Ann. Rep. Geol. Surv. Ohio, 1870, p. 67.

condition in the "bottoms" of large and small streams alike. The fragments in the underclay, mentioned by Barrois, Ashley and Gresley, were not deposited with the clay but before it; their distribution is wholly similar to what is seen now. The mode of transference to the coal, as described by Barrois, is in accord with what one may see in actual bogs; once transferred by plants rooted in the underclay, they would be removed successively into higher portions by plants rooted in the bog—for there is every reason to believe that the Coal Measures plants had as much liking for peat soil as is shown by many towering plants of the present day.

At the same time, the writer recognizes that the suggested explanation is not altogether satisfactory at some localities, where the required conditions cannot be proved.

Microscopic Features of Coal.

The unaided eye can discern many features of coal in the bed; it can group types into glance, matt, cannel, fusain; at times, it can find relations between a certain type of coal and the plants which produced it, so gaining insight into possibly contrasted origin of glance and matt coals; it can recognize great difference of physical features in the several benches of a coal bed, which lead to conviction that each bench may have had its own peculiar history, may have been formed under its own peculiar conditions, very different from those of the other benches. But one quickly discovers that intimate structure of coal can be ascertained only by aid of the microscope, since to the unaided eye, the great mass of coal is wholly structureless.

Nicol and Witham appear to be the first to apply this method of investigation, which Witham utilized especially in studying the structure of fossil plants. Hutton was the first who made a study of the coal itself. In a slice of coal, prepared by Witham, Hutton[89] observed some remarkable cells within the portions which showed no vegetable structure. He made sections of the coals mined at New-

[89] W. Hutton, "Observations on Coal," *Proc. Geol. Soc. London*, Vol. I., 1834, pp. 415–417; also in *Lond. and Edinb. Phil. Mag.*, Vol. II., 1833, pp. 302–304.

castle. These are, 1, Rich caking coal, which is the most abundant and the best in quality; 2, Cannel or Parrott or Splint; 3, Slate coal, consisting of the others in alternating layers so as to give a slaty structure. Vegetable structures can be recognized in all; but besides this, all show cells filled with wine-colored material, so volatile that it can be expelled by heat before any change takes place in the other constituents. The caking coal contains very few and those are elongated; he supposed that originally they were circular and that the changed form was due to pressure. The finest portions of the coal, in which "crystalline" structure is best developed, show no cells; the crystalline structure indicates a more nearly perfect union of the constituents, a more nearly complete destruction of the original plant texture. The Slate coal contains two kinds of cells, both filled with bituminous material; one kind is that seen in the caking coal, but the other is in groups of smaller cells, elongate circular in form. The first type occurs rarely in cannels and related coals, where the whole surface of the section is covered with an almost uniform series of cells of the second type, filled with the bituminous matter and separated by thin fibrous divisions. He was led by these features to believe that difference in coals is due to difference in the original plants. Another type of cells, empty, seem to have contained gas. It is clear that Hutton recognized a structureless portion of the coal containing plant fragments, of which the texture is still recognizable. He made no effort to explain the origin of the bituminous material.

Link[90] found vegetable structures in all coals and recognized that coal is made up of woody matter, usually much comminuted; but in some the structure is loose like that of modern peats, while others are dense like some denser peats of modern origin. Bailey in 1846 and Goeppert in 1848 described vegetable structures in coal. Dawson's[91] first important publication bearing upon the subject was in 1846 but his studies were continued for many years thereafter.

[90] H. Link, "Ueber den Ursprung der Steinkohlen und Braunkohlen nach mikroscopischen Untersuchungen," *Abh. k. Akad. Wiss.*, 1838, pp. 33–44.

[91] J. W. Dawson, "Notices of some Fossils found in the Coal Formation of Nova Scotia," *Quart. Journ. Geol. Soc.*, Vol. III, 1846, pp. 132–136; "Acadian Geology," 2d ed., 1878, pp. 393.

He rejected the use of prepared sections and resorted to the chemical treatment employed by Goeppert. The coal was broken up and the vegetable tissues were separated so as to exhibit their characteristics. He selected for study only specimens which in each case consisted of a single plant, so that he was enabled not only to ascertain the structural features of many forms but also to determine in great measure the share which each type of tissue had in making the coal. Reinsch, in 1881, utilizing prepared sections, elaborated Hutton's work and discovered great numbers of what he took to be very humble forms of vegetation.

Grand'Eury[92] laid emphasis on the vast proportion of amorphous material, the vegetable jelly, which holds the still recognizable plant remains. Clearly, much of the vegetable material was transformed into a kind of pulp, which forms a large part of the coal. "The great number of organs preserved in the form of teguments gives an idea of the quantity of vegetable jelly, which one finds to have formed the coal, in proportion to the epidermis material which is contained there." This jelly was not always so fluid or so homogeneous as to destroy all traces of vegetation for those are still recognizable. In the following year, von Gümbel[93] published the results of his elaborate studies of the fossil fuels from peat to anthracite. Throughout the whole series he recognized the amorphous material, Carbohumin, clearly the vegetable jelly of Grand'Eury, the pulp of H. D. Rogers. He employed chemical processes to disintegrate the coals and to lay bare the vegetable structures, remaining in the enclosed fragments. He was enabled to show that while the glance coal consists of different kinds of vegetable matters, the predominating substance is the parenchymatous cells of the rind, along with tissue like wood, parts of leaves, epidermis flakes, separated disks and spore-like bodies, the whole enclosed in amorphous material. It is probable that the plant remains have been converted so thoroughly into homogeneous coal that determination of any vegetable

[92] C. Grand'Eury, "Memoire sur la transformation de la houille," *Ann. des Mines*, VIII., Vol. I., 1882, p. 109.

[93] C. W. von Gümbel, "Beiträge zur Kenntniss dur Texturverhaltnisse der Mineralkohlen," 1883.

structure is very difficult. The matt coal consists mostly of prosenchymatous cells, which von Gümbel thinks derived from parts of leaves; much epidermis material is present along with spore-like bodies and broken fibrous coal. His conclusions in respect to these matters are like those reached by Dawson. Von Gümbel proved definitively the intimate resemblance of cannel, boghead and other forms to each other and to the Lebertorf of East Prussia. He recognized algæ-like forms along with spores in bogheads and cannels, thus anticipating much which has been published in later years. His figures illustrate well the characteristic forms, but evidently he had doubts respecting the relations, as he refrained from applying names to the forms.

Morris, Wethered and others early recognized spores in coal and some were inclined to attribute to these a very important share in the accumulation of coal beds. They seem to be in all coals. Nathorst[94] found macrospores very abundant in the great coal of the Devonian on Bear Island, south from Spitzbergen. Wethered and some others were regarded by Newberry and by Dawson as placing too much stress on the contributions by spores; while recognizing that spores are almost always present, and at times even in large numbers, they thought that these hardly deserve consideration as important constituents of coal. Kidston[95] has presented the matter in a simple way, which seems to meet requirements. He says that the quantity of spores from the lycopods was unquestionably enormous, and that they entered largely into the formation of some coals. There are bands composed wholly of megaspores and of microspores, varying in thickness from a mere membrane to a centimeter or more. In coal broken transversely, they give a zoned appearance, the bands of spores being distinguished by their dull color within the brilliant coal.

Van Tieghem,[96] in studying sections of flint concretions prepared

[94] A. G. Nathorst, "Zur der devonischen Flora der Bären Insel," *Handl. K. Svens. Vet. Akad.*, B. 36, No. 3, 1902, pp. 40–43.

[95] R. Kidston, "Les végétaux houillers recueillis dans le Hainaut belge," *Mem. Mus. Roy. d'Hist. Nat. de Belgique*, Tome IV., 1911, p. 208.

[96] Ph. van Tieghem, "Sur le ferment butyrique (Bacillus amylobacter) a l'epoque de la houille," *C. R.*, Vol. 89, 1879, p. 1102.

by Renault, made the capital discovery that bacilli existed in Coal Measures time. Renault elaborated this observation afterwards in some memoirs which are captivating in style. The studies of bogheads and related types by C. E. Bertrand and Renault fully confirmed the results presented by von Gümbel, while more recently new confirmation has come through the investigations by Potonié.

For the most part conclusions reached after microscopic study of coal concern chiefly the question as to the origin of the coal; some of them will find place on a later page. It is well, however, to consider the origin of the mineral charcoal or fusain, as that material has been deemed important in some of the hypotheses which will demand attention. It is present throughout the series of fossil fuels, even in peats, sometimes scattered in fragments, minute or considerable, scattered through the mass, at others forming distinct layers more or less persistent and up to 2 or 3 inches thick. Two partings in the Pittsburgh coal bed, continuous in an area of not less than 2,000 square miles, consist in most of that area of mineral charcoal mingled with impalpable mineral matter. The term mineral charcoal well describes the material; the vegetable structure is distinct, the substance is soft and soils the fingers.

Rogers[97] thought that leaves and fronds were brought to the marsh by winds or tides and that such parts as were not reduced quickly to condition of pulp, might remain as mineral charcoal, if the volatile constituents were removed rapidly. Three years later, Daubrée[98] studied fibrous coal from Saarbruck near Altenkirchen. Some specimens are pure black, with the fibers very fine, and resemble charcoal but are more tender; the fragments are irregular, angular and show little rounding of the edges. There is no transition between this and the surrounding coal and, according to Schimper, the fibers suggest those of coniferous wood. At the same locality is a dense type, less black, less brittle but very like charcoal; it contains 48 per cent. of ash. The material bears no resemblance

[97] H. D. Rogers, "Origin of Appalachian Coal Strata," etc., p. 462.

[98] A. Daubrée, "Examen de charbons produits par voie ignée à l'epoque houillere et à l'epoque liasique," *Bull. Soc. Géol. de France*, II., Vol. III., 1846, pp. 153–157.

to coke, to coal changed by dikes of igneous rock. He is certain that this fibrous coal could not have come from spontaneous decomposition of fibrous twigs, for in that case it would be like the enclosing coal. It is remarkably like the ordinary wood charcoal made by fire and it differs from coal as well as from anthracite by the structure and the volatile content. The ash varies from a trace to 70 per cent. He thinks that this fibrous coal is evidence of fires and refers to a great conflagration in 1844 near Saint-Leon in Landes, which was caused by lightning and destroyed 100 hectares of forest. In the discussion, A. Pomel dissented from Daubrée's conclusions because the quantity of this anthracitic fibrous material is too great to be the result of forest fires.

Dawson in 1878 summed up his conclusions which had been published in various forms in the interval from 1846. There is no possibility of accounting for a substance, so intimately mixed with the coal, by the supposition of conflagrations or of subterranean heat. The only satisfactory explanation is that afforded by the chemical changes experienced by woody matter, decaying in the presence of air, as described by Liebig. Mineral charcoal results from subaerial decay, the compact coal from subaqueous putrefaction, more or less modified by heat and exposure to air.

Grand'Eury[99] found fusain present in great quantity scattered in small patches throughout the coal. Stems of *Medullosa* and *Dadoxylon* are often carbonized and whole trunks of *Calamodendron* have been found converted into fusain enclosed in a crust of coal. Fusain is like charcoal; but some of it was exposed to moisture and dryness alternately. The subdivision of the material suggests the breaking up of wood in dry air; he thinks it indicates an extreme climate, for one does not find fusain in recent lignite or in swamps of today, but he has seen it in the older lignites. In any case it came at first from disintegration in air; other causes cooperated, but maceration does not give fusain.

Von Gümbel's conclusions are similar; the mode of occurrence, its peculiar disintegration and its loose structure show that it was in completely converted condition when taken up by the coal. He is

[99] C. Grand'Eury, "Memoire sur la formation," etc., pp. 106, 113–115.

inclined to believe that it was formed in free air, exposed to heat and moisture. Fayol[100] found fusain very abundant in the Grand Couche of Commentry. It occurs in isolated or grouped fragments between bright and dull laminæ, sometimes in heaps several meters long and 10 to 20 centimeters thick; he found it in the axes of brilliant laminæ of branches, especially of *Cordaites,* and in very numerous small fragments in the cannel. Fayol presents many facts which lead him to believe that fusain was formed by decomposition of plants in the air.

This material has been regarded by many writers as anthracitic. Perhaps it may have been so before burial, but the supposition that it could not be impregnated with substances coming from decomposition of the surrounding vegetable material seems to be disproved by McCreath's[101] analyses. At the same time it contains usually less volatile matter than is found in the enclosing coal, showing apparently that its origin was different. The analyses show a volatile content of from 6.40 to 30.74 per cent. The highest proportion is in specimens from a coal bed underlying the Homewood sandstone, in which the volatile is 48.140; a specimen with 11.36 is from a coal with 26.500; but there is one result, the average of several analyses, which gives 20.98, while the surrounding coal has only 17.070; the lowest, 6.40, is from a coal containing 21.410; while in one anthracite coal, the fusain contained 8.60 while the coal itself had 8.830. It is sufficiently evident that the volatile of the mineral charcoal bears relation in quantity to that of the enclosing coal.

The suggestion that mineral charcoal was derived from forest fires cannot be accepted as a possibility. The quantity produced by a forest fire is comparatively insignificant. The writer is sufficiently familiar with the subject to form a judgment. The Indians were accustomed to set fire to forests in many portions of the Rocky Mountains in order to drive the game to lower levels. The fires destroyed the bark and leaves but left the trunks little more than scarred. These remained upright until, weakened by decay, they were overturned by the wind to form the "laced timber," which was

[100] H. Fayol, "Études," etc., pp. 149, 177.

[101] A. S. McCreath, Sec. Geol. Surv. Penn., Rep. *MM*, 1879, pp. 106, 107.

always a terrible obstacle for exploring parties. Equally in the White Mountains of New England and in many portions of the Appalachians, the writer has seen forests of bare stems projecting above the young growth in areas which had been devastated by fires. The coals of Iowa and Missouri, in some beds, contain so much mineral charcoal that one would have to imagine a continuous conflagration for the whole area during accumulation of the coal.

Variations in Chemical Composition.

The independent history of the several benches of a coal bed is shown not only by the physical contrasts but also by the contrasts in chemical composition, which often are very great. Study of these makes evident that the period of time represented in some localities by a half-inch parting of mineral charcoal and impalpable clay may have been so long as to bring about serious changes in the surrounding conditions. Here one is concerned only with contrasts which seem to be original and not with those which may be due to influence of agencies belonging to later times.

The Bernice coal basin in Sullivan county of Pennsylvania is almost 40 miles from the anthracite area and the dips are extremely gentle. The area is insignificant, 600 yards wide and 2,400 yards long; yet it affords illustrations of differing composition which show the influence of very local conditions. The basin was described by Platt and the analyses were made by McCreath.[102] Platt's section shows two coal beds separated by 65 feet. The lower, 2 feet thick, has

Water	4.130
Volatile matter	15.270
Fixed carbon	67.362
Sulphur	0.523
Ash	12.715

with a fuel ratio of 1:4.41. Another analysis from a different part of the mine has very slightly less volatile but 3 per cent. more of

[102] A. S. McCreath, Sec. Geol. Surv. Penn., Rep. *MM*, 1879, pp. 82, 94, 97; F. Platt, ibid., Rep. *GG*, pp. 176, 189–193.

ash. This coal does not coke and the rather voluminous gas burns with a feebly luminous flame. After drying at 225° F., the coal absorbs water rapidly, regaining within 2 hours about 60 per cent. of the quantity originally present.

The higher bed, known locally as Coal *B*, gives as the average of the three benches a fuel ratio of 1 : 10.289, an anthracite according to the ratio but an ordinary bituminous coal in appearance. The three benches show no notable difference in composition and the gases burn with feebly luminous flame. One mile away, a coal bed was seen, whose relations to the others could not be determined. At one opening it has 14.085 of volatile and 16 per cent. of ash, the fuel ratio being 1:4.57, and the gas burns with a non-luminous flame. At another opening the structure is, coal, 1 foot 3 inches, slate and fireclay, 6 feet, coal, 3 feet 8 inches; McCreath analyses show for the benches

	Water.	Volatile.	Fixed Carbon.	Sulphur.	Ash.
Upper bench	7.930	21.410	54.099	0.551	16.010
Lower bench	2.910	11.780	81.672	0.598	3.040

Ignoring the water and ash, the results are,

Upper bench	28.354	71.646	1 : 2.57
Lower bench	12.606	87.394	1 : 6.93

These Bernice coals, belonging in the lower part of the Pennsylvanian, differ from those in other small areas within Sullivan county, which, with fuel ratio of about 1 : 6, yield gas burning with brilliant flame. All are approximately at the same horizon. McCreath's reports contain many illustrations of noteworthy variation in composition of the benches.

The Spitzbergen coal[103] of Jurassic age is in appearance a typical coal. The bed mined in 1904 on Advent Bay is double; the upper bench averages about 3 feet and shows the same features throughout; the lower bench is 1 foot thick. The coal from the upper is

[103] J. J. Stevenson, "The Jurassic Coal of Spitzbergen," *Ann. N. Y. Acad. Sci.*, Vol. XVI., 1905, pp. 85–89.

hard, grayish black and with a fracture more or less conchoidal; while that from the lower is black, lustrous and somewhat prismatic, with some mineral charcoal. These coals were analyzed by A. S. McCreath, who obtained as the average of several determinations for each

	Water.	Volatile.	Fixed Carbon.	Sulphur.	Ash.
Top	3.310	19.790	62.763	0.467	13.670 gray
Bottom	4.696	28.560	57.171	0.413	9.160 light brown

The fuel ratio for the top is 1:3.17 and that for the bottom is 1:2, there being a difference of somewhat more than 9 per cent. in the volatile matter.

Gruner says that the Grande Masse of the Rive-de-Gier formation is double, the benches being separated by the "nerf blanc," a white sand parting less than one third of an inch thick. The lower bench or "rafford" is hard and dull, suitable for use in grates, but the upper or "marechal" is tender, brilliant, less rich in oxygen and employed in making gas and coke. There is very great variation in the several parts of the Grande Couche at Decazeville but, according to Fayol, the Grande Couche at Commentry seems to approach homogeneity throughout.

Barrois,[104] interested by the work of Muck, Stainier, Strahan and others bearing upon this question, secured analyses of the coal from several beds near Aniche (Nord), the samples being taken for each decimeter from roof to floor. The ash varied in one bed from 2 to 8 per cent.; in another from 2.2 to almost 8; in a third, from 1.6 to 11.6 and in a fourth from 1 to 6.4—the faux-toit and faux-mur being neglected. The beds are thin, from 0.6 to 1 meter, and the samples were taken without reference to the partings. The results show definitively that conditions were not the same throughout the accumulation of even a single bench. The volatile in different parts of a maigre coal varied 6 per cent. and in a demigras coal, 8 per cent.

[104] C. Barrois, "Observations sur les variations de composition du charbon dans certaines mines d'Aniche," *Ann. Soc. Géol. du Nord,* Vol. LX., 1911, pp. 177–186.

Reports on composition of coal show similar variations in all coal fields.

Some coals cake when heated, others do not. The available methods of analysis lend no assistance toward explanation of the difference. Some have supposed it to be physical, that the glance or caking laminæ are separated so completely by the dull laminæ that fusion becomes impossible; but this can hardly be regarded as established, for in some portions of the Connellsville basin, the coal cannot be distinguished in hand specimens from the non-caking coal of Massillon, Ohio, yet it yields the standard coke. Nor does the proportion of mineral charcoal seem to be important, since the caking coal near Uniontown, Pennsylvania, has as much as some non-caking coals of Missouri. It has been suggested that the Cretaceous coals of Colorado and New Mexico are caking in some localities, non-caking in others, because of the nearness or distance of igneous rocks. Unquestionably, there is much to be said in favor of this suggestion, yet there is much room for the other suggestion that possibly coincidence may have been mistaken for cause and effect. It is not certain that the influence of dikes can be exerted very far through coal or the accompanying rocks. Several of the coal beds in southwestern Pennsylvania are of caking coal, while there are others in the immediate vicinity whose coals are non-caking. There is no reason to suppose that eruptive rocks have exerted influence there. Incomplete conversion of the material as shown by the action of caustic potash is supposed by some to account for non-caking property, there are coals of Cretaceous age, which are attacked energetically by caustic potash, yet make a firm coke. The suggestion has been made that possibly the presence or absence of sapropelic material may determine the extent of caking. This is possible.

The analyses by Carnot[105] led him to interesting conclusions. He procured 18 samples of coal from Commentry, representing several genera of plants. Ultimate analysis showed that the elementary composition of these coals is almost accurately the same throughout,

[105] Ad. Carnot, "Sur la composition et les qualités de la houille, en regard à la nature des plantes qui l'ont formée," *C. R.*, Vol. 99, 1884, pp. 253–255.

but proximate analysis showed great differences in volatile constituents, due to difference in combination of the elements. Ignoring the ash, he found the volatile and the coke as follows:

Calamodendron	35.3	Well agglomerated.
Cordaites	42.2	Rather swollen.
Lepidodendron	34.7	Well agglomerated.
Psaronius	39.5	A little swollen.
Ptychopteris	39.4	A little swollen.
Megaphyton	35.5	Well agglomerated.

He found similar contrasts in modern woods, almost identical in composition, and his conclusion is that plants preserved in coal appear to have different properties though having the same elementary composition, and that external influences were not the only ones affecting the composition and character of the coal. A casual examination of the table might lead one to suppose that the proportion of volatile matter had its influence on the tendency to cake, since the well-fused coke was given by coals with about 35 per cent.; but this may be only a coincidence. Washed "slack" from the Pittsburgh coal at Laramie, Pennsylvania, contains, without ignoring the ash, as high volatile as even the *Cordaites* coal of Commentry; it was tested extensively more than a third of a century ago, its coke was strong and with it some extraordinary runs were made in a furnace, 100 feet high. All that one can say is that caking may be due to the presence of special hydrocarbons—a sufficiently safe and at the same time a sufficiently broad suggestion.

The Inorganic Content of Coal.

The ash or incombustible portion of coal varies in quantity and composition not only in different beds but even in the same bed, horizontally as well as vertically. It may be fine, powdery, a constituent of the coal itself, or it may be coarse, cindery, coming in great measure from slates or partings. Glance coal is often almost free from ash but the matt coal always has more while the cannels very often have a high proportion.

In making an effort to compare coals, one is dependent neces-

sarily on such analyses as can be reached; but here, at the very outset of the inquiry, the worth of these analyses is a matter of doubt. Formerly, samples were selected at random, fragments taken from a heap were supposed to represent the average of the bed. For many years, however, sampling in the United States has been on the commercial basis and very frequently the effort has been to ascertain the run of mine composition. Analyses of samples collected according to the different methods are, evidently, not of equal worth for comparison, though it must be conceded that in a very great proportion of cases, results obtained by the old method are remarkably like those obtained by the new.

Allied to this is the other query as to how much of the deposit is to be considered in determining the impurity of the coal. There are those who, in a discussion like this, would throw out of consideration all partings, thick or thin, and would consider only the coal itself, holding that partings, as interruptions in the process of formation, have only indirect bearing on the subject. But others maintain that no part of the bed should be neglected, as the deposit must be considered as a whole. There is some degree of propriety in each contention. Study of the coal itself gives a nearer approach to the nature of the vegetable material forming the coal, it may give approximately a conception of what may be termed the original inorganic material; while study of the whole deposit may give a clue also to foreign matters introduced during formation. Yet one finds himself confronted at once by a question as to the significance of partings; in one locality they may be mere films of fusain and impalpable clay separating benches of the bed, whereas in another, one or more of these partings may have swollen to a mass of shale or sandstone or both, many yards thick. Some coal beds, like the Waynesburg, have clay partings, 6 to 12 inches thick. Occasionally one of these persists after the underlying or overlying bench has disappeared. The question arises Should the sample be taken where the partings are thin or where they are thick? Should the sample be taken where the bed is practically single and another where the bed is divided, the latter to include the intervening sandstone, shale and perhaps limestone?

Comparison of analyses means not much unless one knows the method of choosing the samples; no definite conclusions respecting conditions under which coal was deposited can be based on a mass of analyses gathered indiscriminately from all quarters of the globe. It might be that the ash would tell much, if all portions of a bed were studied, each by itself; but even then the information might be too localized. Another difficulty is that published analyses, with a small proportion of exceptions, are of coal supposed to have commercial value, so that they do not give a proper conception of the character of the greater part of coal beds. Thus, Stainier[106] compared 2,568 analyses, gathered from reports on coal areas in Europe and America. Of these only 15 per cent. showed more than 10 per cent. and less than 2 per cent. had more than 20 per cent. of ash. It is very certain that the 2,250 analyses, giving less than 10 per cent., were not all made of prisms representing the whole bed; and equally that the coal was taken from localities which were promising from the commercial standpoint. This is beyond dispute, since more than one half of the analyses report 5 per cent. or less of ash. It is unsafe to take the average of such analyses as representing a probable average condition. Most of the coal horizons show extreme variations which at times are abrupt, so that, while a sample from one locality may have but 5 per cent., another, only a short distance away, may have 25 per cent. It is quite probable that if analyses were made of all the coal beds in some small areas of southwestern Pennsylvania, where the column is long, the results would show that more than half of the beds have more than 10 per cent. of ash. One must recognize that in many localities the conditions did not favor the accumulation of clean coal; in the higher portions of the Coal Measures, within the bituminous region, the beds are all poor, broken by thin slates, no analysis showing less than 12 per cent. and most of them above 16 up to almost 32.

The difference in ash-content of the benches of a coal bed may be very great. A. S. McCreath's analyses of several beds in Pennsylvania show, for those in the Allegheny, differences between the

[106] X. Stainier, "Notes sur la formation des couches de charbon," *Bull. Soc. Belge de Géol.*, Vol. XXV., 1911, P. V., pp. 73–91.

upper and lower benches of 16, 13, 14, 12, 11, 9, 8, 7, 5, 4, 3, and 2 per cent. Sometimes the upper, at others, the lower is the less clean. Often there is no difference in appearance but usually the cause of greater impurity is distinct, for the filmy partings of black shale are apparent. Local variations are equally well marked in analyses by the same chemist. The ash in the Lower Freeport varies from 1.80 to 10.53 per cent. and in the Middle Kittanning from 3.48 to 12 per cent., the samples in every case being of coal which is mined. It must be evident that a collection of analyses from all regions cannot be utilized for generalization. Conditions varied locally at each horizon, so that while worthless coal was accumulating in some places, good coal was accumulating in others; equally, the conditions varied greatly during the period of formation, so that one bench may be clean and another worthless.

But a promiscuous collection of analyses is not merely worthless as a basis for generalization, it is also very apt to be misleading by diverting one's attention from consideration of the features which are really important. One is not concerned with averages of coals all over the world or in the proportion of analyses showing more or less than 5 per cent. The really important matter is the composition of a particular deposit within a large area. When this has been ascertained, one finds that the difficult problem is not to account for the excess of ash but for the astonishing deficiency in ash, observed in some beds throughout very great areas. Analyses by A. S. McCreath and by Hite and Patton[107] show that the Campbell's Creek coal bed in 4 counties of southern West Virginia gave as the result of 26 commercial samples, 5.943 per cent. of ash and all were of outcrop coal, yet 10 of them had less than 5 per cent. In 4 other counties, the average of 34 commercial samples is 5.52 per cent. and several had less than 3. Commercial samples of the Pocahontas coal from 38 localities in southern West Virginia showed from 2.34 to 9.58 per cent., with an average of 4.63. The Pittsburgh usually has 7 per cent. or less. All of these are in areas of from 2,000 to 6,000 square miles or more. Evidently there are coal beds which in

[107] W. Va. Geol. Surv., Vol. II., 1903, pp. 695, 696; Vol. II. *a*, 1908, pp. 393, 394.

immense areas have not so much ash as one should expect; they have less than the original plants should have contributed. This is the important matter for consideration; there is no difficulty in accounting for high ash in coal, but there is great difficulty in accounting for coal which, in areas of thousands of square miles, have too little ash.

The ash in different beds as well as in different parts of the same bed may show notable differences in composition. The White Ash coal bed, of Upper Cretaceous age, near Cerillos in New Mexico, is of interest because in the mines one can follow the coal in its passage from high grade bituminous, thoroughly caking, with 39 per cent. of volatile, and 5.24 of ash, to a typical anthracite with 93 per cent. of fixed carbon and 5.78 of ash. This change takes place within little more than 2,000 feet and is due to influence of a sheet of andesitic rock. Church[108] analyzed the ash from both types, the samples being taken from car-load lots and representing the coal as shipped to market. His results are:

Silica	26.93	32.14
Alumina	32.41	36.58
Oxide of iron	3.96	12.86
Lime	24.68	8.19
Magnesia	10.32	5.11
Sulphate of calcium	0.21	0.18
Soda		1.36
Potash	1.49	3.59

McCreath[109] has given the composition of ash from 2 samples of Red Ash and 7 of White Ash anthracite which may be compared with that from the bituminous Upper Freeport at 3 localities in Jefferson and Clinton counties.

The bituminous coals contain 4.150, 3.100 and 9.125 per cent. of ash respectively. A series of 21 analyses given by Muck[110] show similar though greater variations. The silica is from 1.700 to 53.600; alumina from 2.210 to 41.110; sesquioxide of iron from

[108] W. D. Church, cited in J. J. Stevenson, "The Cerillos Coal Field," *Trans. N. Y. Acad. Sci.*, Vol. XVI., 1896, pp. 117, 118.

[109] A. S. McCreath, Rep. *M*, p. 27; Rep. *MM*, p. 375.

[110] F. Muck, "Die Chemie der Steinkohle," pp. 98, 99.

	Red Ash.	White Ash.	Jefferson.		Clinton.
Silica	47.190	48.250	44.82	39.25	47.585
Alumina	35.522	36.177	42.41	39.20	40.117
Oxide of iron	4.700	3.290	5.30	13.55	6.143
Lime	3.640	1.950	1.44	3.87	0.960
Magnesia	0.965	0.921	3.90	2.90	0.731
Sulphuric acid	0.712	0.490			0.392
Phosphoric acid	1.958	0.923		0.26	0.123
Titanic acid	0.990	0.750			1.190
Alkalies, loss	7.313	7.249	2.13	0.77	1.486

5.590 to 74.800; lime from 1.080 to 21.540; magnesia from 0 to 9.823; potash and soda from 0 to barely 1 per cent. McCreath reports a small quantity of alkalies in nearly all cases. Where the proportion of iron is large the coal is pyritous. Potash is present in all terrestrial plants, though not always as carbonate. Dieulafait[111] examined the ashes of 168 specimens of recent Equiseta collected at various localities in Europe and northern Africa. Alkaline carbonates were wanting but calcium sulphate and potassium sulphate are present in large proportion; yet plants of other types, growing in the same localities, gave ash of the ordinary kind, rich in carbonates and poor in sulphates.

The ash analyses to which reference has been made are for the most part from coals without notable commingling with slates. It is altogether probable that ash from commercial samples would show the same materials, though no doubt in slightly different proportions, as it would contain silts brought in and deposited on the forming coal. But in this connection, one must not forget that wind may contribute towards addition of foreign materials. The presence of atmospheric dust is an only too familiar phenomenon on sea as well as on land, but one is in danger of underestimating its importance. James Douglas has informed the writer that coke from Connellsville, exposed in heaps to the winds of Arizona for a few weeks, showed almost 30 per cent. of ash, though it originally contained not more than 14. This change was in the arid region where dust is abundant, but it suffices to show the possibilities elsewhere.

[111] M. Dieulafait, "Composition des cendres des Equisetacées," *C. R.*, Vol. 100, 1885, pp. 284–286.

Taylor[112] compared the ash of good and bad coal with underclay, bituminous shale and blue shale. The constituents are alike in all though the relative proportions differ. The good coal with 1.36 of ash and the poor coal with 16.9 of ash compared with the underclay show

Silica	59.66	64.21	62.44
Alumina	12.19	28.78	31.22
Sesquioxide of iron	15.96	2.27	2.26
Lime	9.99	1.34	0.75
Magnesia	1.13	1.12	0.85
Potash	1.17	2.28	2.48

Bischof thinks that the analyses show close relationship throughout and that they indicate sedimentary origin for all the materials alike. He says that the variation in composition of the earthy matters in coal is not greater than in shales. McCreath has analyzed many of the Pennsylvania fireclays and the results show great variation, the silica from 47 to 66 and the alumina from 18 to 35 per cent. A similar variation is found in the Pleistocene clays. The resemblance between coal ash and the clays ought to be close in respect of constituents, it matters not whether the coal is allochthonous or autochthonous, but some of the differences offer abundant ground for speculation.

The large proportion of clay in coal ash is, for some, evidence that the material is of extraneous origin, since clay is an extremely unimportant constituent of plants. It is insignificant in the ash from peat. Mills and Rowan[113] give analyses from 27 Irish localities which show in the ash 0.129 to 10.705 of alumina, but 12 of them have less than 1 per cent. and only 3 have more than 3 per cent. It must be remembered, however, that the trees and the peat forming plants of the recent period are not the same with those which gave the coal. The most important plants during Coal Measures time were lycopods and equiseta. Dana[114] cites analyses of some

[112] H. Taylor, cited by G. Bischof, "Elements of Chemical and Physical Geology," London, 1854, pp. 268, 269.

[113] E. J. Mills and F. J. Rowan, "Chemical Technology," *Amer. Ed.*, Vol. I., 1889, pp. 16–18.

[114] J. D. Dana, "Manual of Geology," 4th ed., 1895, pp. 74, 75, 663.

forms belonging to those types, which show for lycopodium ashes 22 to 57 per cent. of alumina and 10 to 14 per cent. of silica; for Equisetum, no alumina but 41 to 70 per cent. of silica. The ash of lycopods is 3.2 to 6 per cent. of the dried plant; of ferns, 2.75 to 7.56; of equiseta, 18.71 to 26.75. Stainier cites Wolff, Czapele and Violette; lycopods have 4.70 to 6.10 per cent. of ash; conifers contain very little ash in the wood but their bark and leaves have much more, the former from 1 to 2 and the latter, from 5 to 7 per cent. Coville[115] has given a table of analyses, showing the quantity of lime in leaves of trees, the percentage of the dried leaf varying from 1.73 in the red oak to 4.38 in the ginkgo, the modern representative of the *Cordaites.*

Lycopods compose the greater part of most coals, other plants giving the less part—though there are beds consisting very largely of *Cordaites.* Dana has calculated that if the original ash were 1.66 of aluminium silicate and if the plant material lost three-fifths of its mass during transformation into coal, there should remain 4.15 of silica and alumina, the total ash being 4.75 per cent. of the coal; and this without introduction of any inorganic matter from without by either wind or water, the whole being derived from the soil in which the plants grew. Coal is known to consist very largely of flattened stems, the cuticle alone remaining; the other parts of plants have been almost wholly decomposed into a structureless pulp, of which not a little may have been removed by solution. Bark and leaves make up a very great part of the coal. One should expect to find in ordinary coal not much less than 6 per cent. of ash, or even more, in which silica and alumina should predominate greatly.

Yet there is the all-important fact that some coal beds in areas of several thousands of square miles have not merely less but even very much less than the normal quantity of ash. The fact that many coal beds have more is unimportant; no one, be he allochthonist or autochthonist, finds any difficulty in explaining the excess of inorganic matter. But the Pittsburgh, Campbell's Creek, to make no reference to some other beds, have less and the condition in those

[115] F. V. Coville, "The Formation of Leafmold," *Journ. Wash. Acad. Sci.*, Vol. III., 1913, p. 80.

beds is not local; they are mined in all parts of their areas and yield scores of millions of tons each year; the analyses are of commercial samples so that they show more ash than the coal itself would show, apart from the thin partings of mud due to overflows. These coals have less inorganic matter than the plant substance should have yielded, which shows that, where accumulation proceeded in a normal way, the product is likely to contain diminished ash. In advancing change by metamorphosis or otherwise the ash is reduced, as appears from analyses of the New Mexico coal and of coals from the anthracite fields of Pennsylvania.

It is wholly probable that not a little of the original inorganic content was removed in solution. Maceration takes much from flax and Fayol ascertained that the same effect is produced on hemp. Wood floated down the Rhine loses much during the journey. Besides this, the organic acids form slightly soluble salts with several bases, which would be removed by leaching. Evidently some areas in southeastern Kentucky, where a coal bed shows less than 1 per cent. ash in commercial samples, must have been in an exceptionally favorable position, where the accumulating coal was protected from flooding by muddy water but exposed to leaching.

The Roof.

The normal roof of a coal bed is shale, often resembling that of the mur in composition but differing in structure.. Roof shale is more or less laminated but ordinarily there is no trace of lamination in the underclay. In what may be termed normal conditions, the passage from coal to roof is gradual, there being a faux-toit, in which foreign matters increase gradually until at the top all traces of coal have disappeared. This may be a bone or a bony coal, with external appearance of cannel, or it may be a coarse worthless coal, made up of alternating layers of bright coal and black shale loaded with leaves or flattened stems. It may be only a few inches thick or it may continue, as in the Pittsburgh bed, through 3 to 16 feet of measures. Sometimes, the passage is abrupt, as seen at the partings or, so to say, the subordinate roofs of a coal bed, which, as has been

seen, often mark crises in accumulation of the mass. Not infrequently the sand and clay laminæ of the roof disappear and the coal is almost a solid layer, but evidence of unfavorable conditions still remains in the high ash.

At many localities the roof shale, composed of fine materials, contains a profusion of plant remains, stems, fronds, leaves, retaining the most delicate markings. Prostrate tree-trunks have been traced in some cases scores of feet and twigs, with the branchlets and leaves attached, have been found in considerable areas, the fossils often as perfect as though they had been preserved in a herbarium; the fronds of ferns at times show all parts in place and as little disturbed as though they had fallen at the foot of the parent plant. The whole arrangement indicates as gentle deposition of the silts as that during overflow of the bottom swamps by muddy water during rise of a Mississippi flood. But this is not always the condition. Renier[116] states that one rarely finds in the Belgian coal fields such remarkable specimens as are described as occurring in other countries. For the most part, the plant remains are fragmentary. So in the Appalachian basin; there are many localities where the remains are beautifully perfect and there are many others in which the remains, though retaining the delicate surface markings, are fragmentary and distinctly not in place. The silts were not deposited as gently in some places as in others. Occasionally vertical stumps are seen, with their roots spread out in normal position over many square yards and still preserving the fragile rootlets, which pass off in all directions as in a living plant. These erect trunks, standing amid prostrate stems and vegetable debris, such as one finds on the surface of forested swamps, rarely pass upward from the coal. It is true that there would be difficulty in tracing the tree downward in case the peat became structureless coal and that the opportunity to make the effort would be a rare one in a mine worked for commercial output, but occasionally the exposure occurs and a

[116] A. Renier, "Observations paléontologiques sur le mode de formation du terrains houillers belges," *Ann. Soc. Géol. de Belgique*, Vol. XXXII., 1904, Mem., p. 261 et seq.

geologist happens to be present at the time. Wilkinson[117] states that near Newcastle he saw several trunks of trees, up to 1 foot thick and with roots attached, starting from a coal seam and embedded in the strata in the original upright position. More commonly the trees found in the shales with attached roots *in situ*, though of the same general character as those making much of the coal, are not rooted in the coal itself but in the shale. In not a few cases, their relations suggest that they grew on spaces covered with detritus, such as one sees in the large forested swamps, where trees, belonging to species rooting indifferently in peat or in inorganic matter, are growing on sand or clay-covered spaces and with their roots extending beyond to the peat itself. Partings in coal beds unite in themselves the features of roof and floor; at times they contain abundance of plant remains and still serve as soil on which a new vegetation arises. Renier has given an illustration. The roof shale of a coal bed is about 4 feet thick. It contains 12 species of plants but, at a little way above the bottom, there appear in addition *Stigmariæ*, which increase in number toward the top where one reaches another coal bed. In some cases the rootlets of *Stigmaria* have pierced the leaves of other plants, but in most cases they have avoided that exertion and have moved around them. Robb, Williamson and others have described *Stigmaria* rooted in parting clays and Williamson has told of a stem rooted in the parting and passing upward into the coal.

The roof shale varies in color from gray to black, is usually quite fine in grain and argillaceous, though often notably arenaceous. The features are as characteristic in later formations as in the Coal Measures. The dark color is due to organic matter, which is not always derived wholly from land plants, since the deposit at times is not of flood-plain origin. The roof of the Upper Freeport coal bed exhibits the contrast. In extensive areas, it is of the ordinary type, with reasonably well preserved plant remains, but, at some widely separated localities, it contains along with very fragmentary plant remains great abundance of marine fossils, belonging to types

[117] C. S. Wilkinson, "Mines and Minerals Statistics of New South Wales," Sydney, 1875, p. 130.

commonly regarded as requiring deep water. The Middle Kittanning in much of Ohio is easily recognized by means of its marine shale roof. Lesquereux has mentioned several instances in Kentucky and the Pennsylvania geologists have added many more. Absence of plant remains is reason for suspecting that the shale is not a terrestrial deposit, even though remains of animals appear to be wanting. Boulay[118] was puzzled in several instances by a roof apparently normal but without trace of plants. Very close examination revealed an exceedingly thin layer with *Mytilus* at 4 or 5 inches above the coal. In many cases within American coal areas, the prevailing forms in the roof are *Lingula* and *Orbiculoidea,* which are shallow water forms, but there are roof shales, usually somewhat sandy, containing *Productus, Spirifer* and other forms which belong to the so-called deep-water fauna. The condition is quite commonplace in modern times. Instances of peat deposits directly underlying marine clays and sands were given on preceding pages and many additional instances could be cited if necessary.

Limestone is by no means an uncommon roof; it is characteristic of several coal beds within the Beaver formation. I. C. White has recorded many instances in Pennsylvania; Orton, Jr. and A. A. Wright have done the same for Ohio and I. C. White reports the same condition at localities in southern West Virginia. At all of these localities the limestone is marine; but contact with the coal is not found throughout, for very frequently the coal and limestone, in contact at one locality, are separated by several feet of shale or even sandstone at others. The lowest coal bed of the Allegheny in Ohio often is in contact with the overlying marine limestone, and the Harlem coal bed of the Conemaugh is at times directly under the marine Ames limestone, though usually a considerable mass of shale intervenes. So in the Illinois field where Worthen[119] found his coals III. and VI. with a marine limestone roof. This is not unusual enough to be surprising; some instances have been reported

[118] l'Abbe Boulay, "Recherches de paléontologie végétale dans le terrain houiller du Nord de la France," *Ann. Soc. Scient. de Bruxelles,* 4me annee, 1879, sep., pp. 33, 47, 57–59.

[119] A. H. Worthen, Geol. Surv. Illinois, Vol. III., 1868, pp. 12–13.

from Iowa and Indiana; Tschernychew and Loutougin[120] state that four coal beds in the Donetz basin of central Russia have marine limestone or calcareous shale as the roof material. Coals of the Monongahela and higher formations frequently have non-marine limestone as the roof material. Lipold has shown that the Triassic coals of his area sometimes have shale but at others limestone roof. Von Gümbel and de Serres have described beds of lignite with limestone roof. Peat deposits have in most cases either clay or sand roofs but calcareous roofs have been recorded on a preceding page.

Occasionally a coal bed is found between marine limestones. Fayol saw at Fontaine near Mariemont in Belgium two beds of anthracite, 3 meters apart, intercalated in marine calcareous shale. He thinks that, according to the *in situ* theory of origin, it would be necessary to suppose that the lower limestone, produced in deep water, was lifted and emerged; then that a submergence of similar amplitude occurred after formation of the first coal bed; that a second emergence succeeded the deposit of 3 meters of limestone and that a second submergence followed formation of the second anthracite bed. Be that conclusion good or not, it is certain that occasionally a coal bed is seen in contact with marine limestone above and below; Illinois Coal VI. not infrequently has this feature, though it must be said that in areas of hundreds of square miles it is separated by several feet of clay below and of shale above. The Tertiary coal at Häring, as well as some south Bavarian coals of the same age, is said by von Gümbel to be between limestones: he thinks that the former was a cedar swamp. Virlet d'Aoust[121] has described the section exposed in a great excavation east from Havre. He saw there 3 characteristic beds of peat, which are merely intercalations in a mass of very calcareous clay, containing abundance of marine shells belonging to *Cardium, Mytilus* and other genera.

It is quite possible also for accumulation of coal to be inter-

[120] Th. Tschernychew and L. Loutougin, "Le bassin du Donetz," Guide des Excur. VIIme Cong. Géol., 1897, XVI., pp. 13, 14.

[121] Virlet d'Aoust, "Note sur le terrain d'atterissements récents de l'embouchure de la Seine," *Bull. Soc. Géol. de France*, II., Vol. VI., 1849, pp. 606–625.

rupted by ingress of marine conditions. The Harlem coal bed at a locality in Ohio and at one in West Virginia has marine forms in the upper part; the condition is common enough in recent times; Belgrand found a peat on the Seine which has many shells and passes upward into a peaty clay and sand, full of shells; Yates described a submerged forest in Cardigan bay where the stems of *Pinus sylvestris* had been bored by *Pholas* and *Teredo*, after which the peat-making was resumed.

Barrois[122] classified the roofs which occur in a portion of the Nord basin. He found, (1) sandstone, an offshore deposit, with casts of trunks and branches of land plants; (2) shale with plants, carbonaceous, remains abundant and well preserved, by their size and distribution showing short transportation—they fell into the mud from plants or were blown by the wind; (3) carbonaceous shale, thin cannel-like, micaceous and pyritous, with remains of fish—the water was brackish, marine or fresh, little disturbed and deposition was slow; (4) bituminous shale, brown, contains pelecypods and crustaceans—thicker than 2 and accumulated more slowly in fresh or brackish water, is often rich in fragmentary plant remains and in fusain; (5) calcareous shale with marine shells, accumulated in deeper waters open to tides. Numbers 1 and 2, which he terms Group *A*, are to be regarded as deposited by disturbed water on a swampy surface, at times dry and never covered with water more than 5 meters deep. The others, forming Group *B*, were deposited in the deeper water of ponds, lakes, gulfs, as shown by the finer grain and the association of plant remains with those of animals.

Erect trees, parallel among themselves, occur frequently in the area examined. If these had been floated in from the land, they should be found almost exclusively in roofs of Group *B*, deposited in deep water; on the other hand, they should be rare in Group *A*, formed in shallow, muddy water, where they would be buried without being able to retain the erect posture. But the studies show that

[122] C. Barrois, "La repartition des arbres debout dans le terrain houiller de Lens et de Liévan," *Ann. Soc. Géol. du Nord*, Vol. XL., 1911, pp. 187–196.

there are no erect trees in the deep water roofs of Group *B*, where only broken plant fragments were seen; whereas they are found in the, at most, shallow-water roofs of Group *A*, where leaves occur, *in situ*, spread out flat and intact. In the collieries at Lens, 19 roofs with plant leaves *in situ* have erect stems: 7 of these roofs contain, elsewhere, fragmentary plant remains and lacustrine shells, but not one of these contain such remains in the localities where they have erect trees. All the erect trees were found in roofs of the Group *A* type; not one was found in any roof which is persistently of the *B* type; 28 such roofs exist in the Lens area and all were studied. At Liévan, 7 roofs of the *A* type have yielded erect stems, but none has been discovered in any of the 17 roofs belonging to the *B* type.

These detailed studies, made in small areas where the conditions are apparent, confirm the opinion of Dawson based upon study of the Acadian outcrops and fully justify the conclusion reached by Barrois; erect trees are not found in deposits laid down in water deep enough to permit floatation; they are found only in deposits on which there was never more than a shallow cover of water.

Irregularities in the Roof.

In all coal beds there are what the miner calls "troubles." Some of these, such as "clay veins" for the most part, are due to disturbance after the column had been deposited, as they pass into overlying rocks; others, irregularities of the bottom, were due, ordinarily, to the uneven surface on which the coal accumulated; but there are many which mark the courses of streams which continued after accumulation of vegetable matter had begun and were obliterated slowly by encroaching plants.

Irregularities in the roof are generally much more perplexing than those in the floor. They are the "washouts," to which reference is made in almost every work on coal fields, and they are closely related to the greater "washouts" or filled valleys. In those to be considered here, only the coal and its roof are concerned. More or less of the coal has disappeared and occasionally the apparent replacement extends even to the underclay. Seen in cross-section,

the foreign material tapers downward as if introduced from above. Often there is no serious distortion, and the coal shows only such irregularity in structure and composition as might be expected if the process of accumulation was more or less interrupted. The variation in the coal is usually such as to indicate that the "trouble" had its origin, at the latest, before the coal was consolidated; but this is not always the case. At the same time, one must not fail to recognize that many times there are disturbances in the immediate proximity, which appear to be directly related to the "washout"; irregular cracks and faultings frequently occur, and the cracks are filled with clay from the partings or even from the "washout" stuff itself. These conditions are due to disturbances of later date; the effect of the force, which caused the gentle folding of the strata, became especially distinct where the mass of resistant rock had been thrust into the brittle coal.

Blandy[123] has described the conditions observed in the Red Bank Mining property in Armstrong county of Pennsylvania. The work of removing the coal from these mines had been made unprofitable by "horsebacks," as the miners termed the rolls of indurated clay descending from the roof. These seldom reached the floor but very frequently and for considerable distances, replaced all but 3 or 4 inches of the coal. It was necessary to ascertain the extent of these troubles before reaching a decision respecting farther continuance of operations. Blandy's systematic survey yielded the results presented on the map, which accompanies his paper. These "troubles" mark ancient water-courses. The chief stream was followed for about 1,700 feet and several well-defined branches were mapped. At the southerly end of the workings, another stream was encountered, nearly 100 feet eastward from the former. These stream-courses diverge northwardly, so that at the boundary of the property they are 1,200 feet apart. In another mine, somewhat farther east, the course of a third stream was followed for more than 600 feet, its branches being traced to varying distances. This stream curved

[123] J. F. Blandy, "On Evidence of Streams During the Deposition of the Coal," *Trans. Amer. Inst. Mining Engrs.*, Vol. IV., 1875, pp. 113–116.

toward the west in its lower portion, so that if the direction were retained, it would be continuous with a tributary of the main stream within less than 900 feet. Several branches were followed to their heads; in each case the channel became shallower and at length disappeared in the roof. At the sides of all the channels, one finds interlocking coal and clay and the adjacent coal is always tender, finely fractured but pure. The indurated clay, filling the channels, passes upward into shale.

Platt[124] has described a complicated channel of this type, seen by him in Westmoreland county of Pennsylvania. A "rock fault" in the Millwood Colliery on the Pittsburgh coal bed was traced for more than 1,200 feet. The roof is a grayish clay shale, which, at the edge of the "fault," descends suddenly through the bed and spreads out on the underclay. The sides slope at 20 degrees and upward. The width of the clay deposit averages 100 feet, but in one crossheading the maximum, 120 feet, was found. Along the median line, wedge-shaped masses of the Pittsburgh sandstone replace part of the clay. Coal is found in the clay at the sides but not elsewhere. Close to the fault, the coal is twisted, hard, lusterless, and has so much slate as to be worthless for fuel. This condition changes gradually away from the clay and at 400 feet the coal equals that from other mines in the region. This description by Platt is that of a filled channel, originally occupied by a stream during the whole period of the Pittsburgh coal, a stream subject to floods and carrying muddy water which left its silt on the vegetation during overflow. The stream became insignificant during deposition of the overlying shale and its narrowed channel was obliterated during the early stages of the Pittsburgh sandstone. Similar "washouts" occur in other mining properties within the district, but their relations have not been worked out.

Descriptions of such channels abound in the reports in several states. Ashley and Udden have recorded instances like those of southwestern Pennsylvania, where the old channel way was filled with a conglomerate mass of pebbles, lumps of clay and coal, with

[124] W. G. Platt, Sec. Geol. Surv. Penn., Rep. *H4*, 1878, pp. xxv, xxvi.

stems and branches of trees. The "horse," about which Buddle[125] wrote many years ago, belongs in this category. This "washout," 170 to 340 yards wide, had been traced for about 2 miles in Colford High Delf seam. The material is sandstone, through which a tunnel had been driven where the width is about 200 yards. Under this "horse," the coal is 4 inches to 7 feet thick and usually it is injured by sand patches from the roof; but it contains no gravel, bowlders or fragments, though the last occur in the sandstone. Some portions of the "horse" consist of sandstone breccia, with pebbles of quartz, like those of the Forest pudding stone—which underlies the Carboniferous limestone—with fragments of coal, ironstone and plant remains. The underclay is wholly regular.

It is unnecessary to cite additional instances. The phenomena are familiar in British, French and German coal fields. They have been observed in the Laramie area of Colorado and New Mexico, and they are characteristic of the vast peat area of the Rhine lowlands, where they have been described by Lorie. All are alike, whatever the age may be; they are the work of sub-aerial streams, some of which existed while accumulation of the vegetable material was in progress, while others began existence at a later date.

Flexed Strata.

The presence of flexed shales or coals between beds of undisturbed rocks has been regarded as evidence of slips or slides of soft material on submerged slopes; but they cannot be accepted as evidence of such conditions until, first of all, the existence of the supposed conditions has been proved in other ways: for this structure is so familiar as to be almost normal in all strongly disturbed areas—in the Appalachian basin, in the Nord basin or in the little basin of Commentry. To bring about the condition there must be a soft, yielding material between beds of more resistant rock. Lohest[126] has shown that movements occur in the coal without disturbance of

[125] J. Buddle, "On the Great Fault called the "Horse" in the Forest of Dean Coal Field," *Trans. Geol. Soc. Lond.*, II., Vol. VI., 1842, pp. 215, 218.

[126] M. Lohest, "Sur le mouvement d'une couche de houille entre son toit et son mur," *Ann. Soc. Géol. de Belgique*, Vol. XVII., 1890, Mem., p. 125.

the roof; one notable case being that of the couche Grande Moisa, near Liége, where the coal is so distorted as to be thrown into a succession of hook-like curves. Briart[127] has given illustrations of similar movements in coal beds of the Nord basin. He had observed the phenomenon also in Italy just beyond the Austrian border. There one finds boghead, with clay beds, between great strata of dolomite, the latter showing throughout the section a remarkably regular dip of 30 to 40 degrees. Aside from this dip, they show no signs of disturbance, but the intervening, yielding rocks have been thrown into complicated folds. Katzer[128] notes a peculiar case; the upper part of a coal bed has been pushed into complex wrinkles, which occasionally affect the whole bed; but there are no wrinkles in the roof. Strahan,[129] in referring to a contorted clay parting between undisturbed benches, remarks "obviously the shale acting as a lubricant, has permitted differential movement between the strata above it and those below it." The explanation is manifest everywhere and is not open to dispute.

The Hypotheses.

The reader who has examined Part I. of this work has discovered that, in most cases, an author regards his hypothesis as wholly satisfactory, as explaining all phenomena deserving explanation. The allochthonist greets joyfully each occurrence of pebbles in coal, of land shells in the rocks, of rooted stumps filled with sand, etc., as so much additional evidence in favor of his doctrine; while the autochthonist is equally elated by such occurrences, which are infallible proofs that his doctrine is correct. Observations at given localities are often contradictory, but there is no reason to assume that any observer has asserted, knowingly, an untruth or suppressed, consciously, a truth; yet it is clear that, in some cases, personal equation has played an important part, there being, apparently,

[127] A. Briart, "Notes sur les mouvements parallèles des roches stratifiées," ibid., pp. 129–135.

[128] F. Katzer, "Notizien zur Geologie von Böhmen," *Verh. k. k. Reichsanst.*, 1904, pp. 150–159.

[129] A. Strahan, "Geology of South Wales Coal-Field," Part V., 1904, pp. 65, 66.

strong elective affinity for facts of one type in preference to those of another. At the same time, when one finds that the hypotheses are wholly antagonistic, he is compelled to believe that some must be wrong, and he is led to suspect that the best may be defective.

In considering the several hypotheses, the writer will take for granted that, as the laws of physics are unchangeable, physical agents have always acted in the same way as now, though at times their activity may have been greater and more prolonged than at others; That a hypothesis, to be acceptable, must not be based on assumptions, which are themselves hypothetical or not conceivable in terms of conditions actually known to exist; That inasmuch as knowledge is still imperfect, no hypothesis, satisfactory in all details, can be framed and that there must remain many matters to be studied by investigators in the future. There is no assertion of uniformitarianism beyond that of physical law.

Defenders of the several hypotheses should meet on equal terms in respect to introduction of evidence. Advocates of one group of hypotheses must not arrogate to themselves the right to utilize one type of evidence while denying that right to their opponents. It is hardly legitimate to denounce as tyranny the doctrine of Modern Causes, on one page, while on a later page of the same memoir, a luckless adversary is swept from the arena by the contemptuous assertion, that nothing of the kind is known in recent times. It must be remembered that, in this study, both inductive and deductive reasoning are required. No man ever explored the Carboniferous forests, mapped Carboniferous topography or sailed a Carboniferous sea. Those who defend the doctrine of Ancient Causes, equally with those who defend the doctrine of Modern Causes, reason from the known present to the unknown past. The starting point is absolutely the same for all. Evidence of every kind must be welcomed and an effort made to determine its value. Stratigraphers may not reject the testimony of palæontologists nor may the palæontologists speak slightingly of the stratigraphers. For either group to dwell lovingly on errors of the other, committed many years ago, is as absurd as is the effort to discredit the work of modern Egyptologists because their predecessors of half a century ago, in their anxiety to reconcile

Egyptian chronology with that of Ussher, committed themselves in blunders now regarded as ludicrous.

In presuming to discuss conclusions reached by fellow-workers, the writer makes no pretence to superior judicial capacity; during the progress of this work he has discovered only too many proofs that his knowledge is defective, his judgment fallible and his mind on the defensive against novel conceptions. His conclusions are merely opinions based on extended observations in many lands during more than 40 years, and on careful study of literature bearing on all sides of the case. They are offered in the hope that they may prove to be of service to some student in the future.

Hypotheses presented to explain the formation of coal beds fall naturally into two groups; one asserting allochthonous origin of the plant material, the doctrine of transport; the other asserting autochthonous or *in situ* origin of that material. The former conception is the older.

Allochthony.

The earliest observers, for the most part, saw in the rocks records of only cataclysmic action; for them, proofs of the Noachic deluge exist everywhere. In cosmogonies from the sixteenth to the nineteenth century, that flood is supposed to have covered the globe as a universal ocean, lashed into fury by winds, so that it tore away forests and bared the mountains; the whole mass of débris was swept into maelstroms, spread over the whole surface and, at length, deposited under selective influence of gravity. The majesty of the catastrophe had grown with the telling, and descriptions had become so vivid that the pictured conditions seemed to be reality. But the ravaging disaster was, in greatest part, imaginary; the Hebrew[130] chronicle relates nothing to enforce the conception. It describes the deluge as merely a rain flood, which destroyed animals by drowning but did not destroy the trees. There is no assertion of violence, for the clumsy ark drifted at ease throughout, the occupants resting apparently in comfort. The idea, however, was normal; all were familiar with the power of rushing waters, so that there was needed

[130] Genesis, Chapters VII., VIII.

only a conception of greater torrents in greater areas to give basis for hypotheses respecting the origin of rocks.

The doctrine of flood action was well-outlined at a very early date. Woodward, at the close of the seventeenth century, had announced that materials, swept from the land, sank to the ocean bottom in the order of their specific gravity; this was emphasized by Scheuchzer, Conybeare and several later writers, but it was disputed earnestly by Williams, as not in accord with the actual succession of strata. Applied to coal, modifications were made as acquaintance with the phenomena became more intimate. Some authors, Voigt, Parkinson and, much later, Petzholdt, thought that the vegetable material had been reduced to fluidity on the land before removal by floods; Sternberg and Boue held much the same opinion, for they thought that vegetable materials had been reduced to a pulp before removal and that the change to partial fluidity was produced in the tepid waters of the primaeval globe. Conybeare apparently was the first to conceive that a single flood might give materials for a coal bed of any thickness, and Jukes was the first to suggest that coal beds may have accumulated on the slopes of a submerged delta. But in all, one finds the conception of floods, carrying at one time mingled organic and inorganic débris, at another, mostly plant materials, but at a third, mostly inorganic substances.

Before undertaking the consideration of allochthony as a doctrine, it is well to examine several hypotheses, which have been defended by some eminent allochthonists but opposed energetically by others.

Mohr in 1866 revived suggestions by Parrott and Bischof that some coal beds might be accumulations of seaweed, and made them into a generalization respecting all coal beds. His reasoning is without reference to the conditions in which coal occurs; the mass of seaweed is incredibly great; there is enough to account for the coal; what has become of it? it has been converted into coal.

But there are some things needing explanation, with which Mohr does not concern himself. The mass of seaweed on the coast of France, Ireland and the Orkneys is enormous and, in all probability, it has always been so since the present climatic conditions began,

but, neither on those coasts nor on those of the North sea, does one find any considerable accumulations of decayed or decaying seaweed. The search in those areas has been rewarded by the discovery of a few deposits, which suffice to show the possibility of accumulation, while they emphasize the improbability. The ocean bottom has been dredged in all directions by exploring expeditions of many nations, but no trace of a deposit has been found in even the areas where seaweed is most abundant. Mohr thinks that the Spitzbergen coals owe their origin to weed transported by the Gulf Stream. There is sufficient reason for doubting the existence of that stream at the time when those coals were formed; but, in any event, if the stream were existing then and as efficient as now, it could not avail for the work. Robert's[131] statements respecting the quantity of weed on the Spitzbergen coast do not bear the interpretation placed on them by Mohr. There may be enough at times, if the wind be right, to make landing on the shelving shore a rather awkward process—it is awkward enough at best—but the quantity is wholly unimportant. Stevenson, in 1904, sailed along the west coast for 150 miles and saw very little seaweed.

In like manner, conditions within the Sargasso sea have been exaggerated. Wierd reports by crews of Columbus's boats, 18 to 40 tons burden, have been repeated with the increment of centuries and have found their way into geological treatises everywhere. Stevenson[132] made two voyages in 1910 across the central part of that sea, where the mass of weed should be densest. The quantity, from the standpoint of Mohr's hypothesis, is utterly insignificant. At times, small patches, perhaps 100 or even 200 feet square, may occur, but they are rare and have brief existence, as they are broken up quickly by the strong trade wind, which keeps the water in constant commotion—the surface being covered almost without cessation by "white caps." The feathery individual bunches of weed, rarely more than 1 foot in diameter, are arranged in lines following

[131] E. Robert, "Aperçu des observations géologiques faites dans le nord de l'Europe," *Bull. Soc. Géol. de France*, Vol. XIII., 1842, pp. 24, 25.

[132] J. J. Stevenson, "The Sargasso Sea," *Science*, N. S., Vol. XXXII., 1910, pp. 841–843.

the direction of the wind. Occasionally, several lines are united into a strip, 5 or 6 feet wide, but the bunches are barely in contact, while spaces of 500 to 2,000 feet intervene between the strips. Within the area, where weed is most abundant, the whole mass, in a width of a mile, would form a strip not more than 65 feet wide, if the bunches merely touched; if the material were compressed, so as to bring the parts of each bunch into contact, the strip would be insignificant, not more than 2,500 cubic yards to the square mile. North and south from this small central area, the quantity of weed is unimportant.

Ochsenius[133] in 1890 made some suggestions, which in later publications he developed into what is known as the "barricade theory." This has been given in detail on earlier pages in Part I. One might hesitate to regard this "theory" as offered seriously; but its author presented it in various forms and discussed it elaborately; some geologists have considered it worthy of refutation, while others appear to have found in it enough of suggestiveness to give it merit. Ochsenius clearly was not familiar with conditions observed in coal deposits and his information respecting river action was imperfect. He cites the statements of writers concerning various localities, but these refer to matters quite irrelevant. The rafts of the Atchafalaya and of the Red river have no bearing upon the question of his dams. The extent and character of those rafts were grossly exaggerated by the early observers, but such as they were, they could not be formed on the rivers imagined by Ochsenius, as they required an enormous drainage area. Of course, barricades could be formed at curves of rivers and they are formed; but they are not such as the "barricade theory" demands. Such a blockade of timber would soon become a dam without lateral spillway, as he suggests; but if it existed long enough, with low water, to permit the fine "Spulgut" passing over to form a bed of carbonaceous shale in the basin, and long enough afterwards, with continuous high water, to permit

[133] C. Ochsenius, "Ueber das Alter einiger Theile der (süd-amerikanischen) Anden. III.," *Zeitsch. deutsch. geol. Gesell.*, Vol. XLII., 1890, pp. 135, 136; "Die Bildung von Kohlenflötzen," ibid., Vol. XLIV., 1892, pp. 84–86, 98; "Die Bildung der Kohlenflötze," *Verh. des. d. Naturf. u. Aertze*, II., 1896, pp. 224–230.

coarse "Sperrgut" to pass over so as to form a coal bed in the basin, it would be no longer a mere dam: it would be a deposit in the channel-way, miles long, which would be impregnable against any flood: the mighty débâcle, which would sweep out the dam and all accumulated material behind it, the "Rollgut," to make a sandstone and conglomerate deposit in the basin, is beyond the reach of imagination. Being in a lowland, little above sea-level, there could not be any such flood as Ochsenius conceives, since high water would give only a comparatively harmless overflow. But at best, the obstruction would cause the river to seek a new channel-way. That was the effect of the Red river raft; the Sudd of the Nile, overturned trees blocking the channel of the Bermejo in Paraguay, obstructions along the upper Mississippi do the same thing; they are not swept out by the high floods, they merely cause diversion of the stream. The breaking of levees along the Mississippi has no bearing on the matter. Those structures have a moderate base in comparison with their height, whereas the barricade, after centuries of accumulation, would be only a few feet high and miles long.

Jukes saw in the Coal Measures of the South Staffordshire field deposits resembling those on a submerged delta cone; his arguments have been presented on an earlier page. Almost a quarter of a century later, Fayol, after long study of the Commentry coal basin, reached similar conclusions, which, in 1888, he presented in such admirable form, with such skilfull attention to detail and with such apparent grasp of all the features and possibilities, that his conception won instant approval from many eminent geologists in all lands and it was accepted as a final explanation of phenomena in the limnic basins of central France. This "Delta theory" merits careful consideration.

According to Fayol, the basin of Commentry was occupied by a lake, 9 kilometers long and 3 kilometers wide, with greatest depth of 800 meters and with an outlet on the southern border. Rain water ate away the surrounding mountainous region and the transported materials are those composing the beds of conglomerate, sandstone, shale and coal now filling the basin. The distribution of those materials was determined by their specific gravity or their

fineness of grain as well as by the condition of the water—quiet or agitated. The finer, lighter materials were carried much farther than the others before reaching the bottom. The basin was filled eventually by detritus from the Colombier at the northeast, the Bourrus at the north and by several less important streams at the north and west; these giving three "zones" of coarse material without coal. Between those "zones" and separated by the Bourrus deposits, are two areas of less coarse deposits, les Pegauds at the east and les Ferrieres at the west, in which the coal beds are found. Petty streams from the north added their quotas, uniting the deltas along the northern border, but practically no material was brought in from the south. The streams were, all of them, short and torrential. The delta-character of the mass is shown distinctly in the Pegauds area by the steep dip of the beds, which approximates closely that of neptunian or submerged portions of deltas; by the presence of fragments of coal, shale and sandstone in the rocks proving gradual advance of the delta-plain; by slips, of which the proof is seen in folded shales, local faultings, evidence of movements of yielding materials on a steep slope; by local erosions; by the clear evidence of great débâcles; and by the structure of the coal beds, which are not parallel. The absence of horizontal alluvial beds on top is due to gradual deepening of the outlet, which amounted to about 100 meters at the close of deposition. Fayol makes no reference in his work to the Decazeville basin, but, as stated in the report of the Réunion of the Geological Society, his theory was applied to that basin by others, who found the evidence as conclusive as that in Commentry.

In considering this doctrine, one must bear in mind that the matter does not concern the existence of deltas in lakes, for that has never been disputed. Nor does it concern accumulation of vegetable materials in one way or another on the alluvial deposits of deltas, for that too has never been disputed. Fayol's doctrine is that coal beds, like other transported materials, were deposited as part of the neptunian or submerged portions of deltas. Granting, for the present, that vegetable matter to give such coal beds could be brought in by the streams, the only question for consideration here is,

whether or not the phenomena at Commentry and Decazeville justify the conclusions embraced in the Delta theory.

The dips of the strata at Commentry are regarded as all-important evidence, since in much of the area they compare with those observed in some lake deltas. But it must not be overlooked that the steep dips, 20 to almost 50 degrees, are those in the Pegauds area, in the supposed bay between the Bourrus and Colombier deltas. Before formation of the Grande Couche, the Bourrus delta had practically crossed the basin, dividing it into two little ponds, of which the eastern or larger may have had an extent of rather more than 2,000 acres. The coal is on the northern border of this pond or bay, while the outlet was on the south side of the basin. The area of the steep dips is nearly 2 miles from the spot where the Bourrus issued from the mountains and three-fifths of a mile west from the coarse rocks of the Colombier deposits. Its rocks are shales and fine-grained sandstones. It is not on the steep delta slopes, but in the quiet "eddy" between the deltas. The dips in such an area should be gentle, not abrupt. Martins states that, within three-fifths of a mile, the slope of the Aar delta in Lake Brienz decreases from 30 degrees to practical horizontality; De la Beche found the Rhone delta practically horizontal at 2 miles from the shore, while the delta of the torrent of Ripaille, formed in deeper water, showed not more than 10 degrees as the average for half a mile. In every case the decrease is very rapid away from the source of supply and the dip is usually quite gentle within less than a mile, though often very steep at the origin. It would be impossible to explain the steep dips in the Pegauds area, if they be taken as original. But one is not left to surmise in order to explain these dips, for they are not original.

The cause is clear enough; they are due in chief part to disturbance accompanying an outburst of eruptive rock in the northeast corner of Pegauds. This affected not only Pegauds but also the Ferrieres sub-basin, about 3 miles toward the west. This outburst took place when the deposition of Coal Measures rocks had been completed and prior to that of the Permian, which is unconformable. This disturbance crushed sandstones and flexed soft shales between

sandstones; in some places it shattered the coal and rubbed the fragments to polished surfaces, at times reducing the coal and shale to a flaky structure like that of pastry. The conditions are those so familiar in the Logan and Pottsville coal areas of southwest Virginia and southeastern Kentucky, as well as in the Allegheny area of Broad Top in Pennsylvania. They are commonplace in some Cretaceous areas at the west. The extent of disturbance increases toward the place of greatest outburst, where one finds faults and slips in abundance. The remarkable "Glissement de l'Esperance" is in no sense due to a slide on the slope of a submerged delta. This glissement marks the course of a valley, eroded after the Coal Measures deposition had been completed. It was filled with materials different from those of the adjacent rocks and extended for a considerable distance toward the southeast. Similar material was seen in a fragmentary exposure along the railroad at about 3 miles northwest. When the eruption took place, these new, light-colored rocks of the valley were folded into a close irregular syncline, the finer dark shales of the valley wall were pushed over into recumbent folds and a sharp horizontal fault was made underneath the syncline; other valleys of similar type were observed in the basin. The structure, in its striking features, is in no wise original and has no bearing whatever on the mode of deposition.

Practically no coal in economic quantity was formed in the Commentry basin until after not less than 500 meters of rock had been deposited. Suddenly one comes to the Grande Couche in les Pegauds, with maximum thickness of not less than 12 meters, and to a similar bed with greater maximum in les Ferrieres—the other and smaller sub-basin. This abrupt appearance of the great coal deposits is a phenomenon for which the delta theory offers no adequate explanation. The streams had brought down a marvelous quantity of inorganic material, converting much of the lake area into dry land and, of necessity, making much of the still water-covered area very shallow. But during this period, no vegetable materials had been brought down, aside from those composing the insignificant streaks of anthracite along the northern border. The new land on the northern side of les Pegauds, barely half a mile

wide, could not have provided material for the coal, as, only a few years earlier, reckoning time as is done in the Études, it had been the scene of a terrific débâcle, which had swept 125,000,000 cubic meters of rock across it and had left the surface strewn with coarse debris. It would seem as though vegetation must have appeared abruptly throughout the drainage area or that the streams must have changed their methods quite as abruptly, so as to devote attention to plants instead of to inorganic materials.

Aside from this, the theory seems to offer no satisfactory explanation of the areal distribution of the coal. Even though the lake had been as deep originally as conceived by Fayol, the pond must have become comparatively shallow prior to formation of the Grande Couche, and the bottom must have fallen off quite gently as it receded from the shore line at the north. One cannot conceive, after reading Fayol's description of the region, that any other condition was possible. The Grande Couche is on this northern border of the Pegauds area, and its present outcrop is less than a mile south from the granite. The outcrop is shaped much like a spreading horse-shoe, with its convexity toward the north. The bed is very thick on the north side of the curve but breaks up into several beds at the west, where it disappears, whereas on the east side it merely thins away. Southwardly, it quickly loses thickness, breaks up and within a short distance it disappears. It is confined to that portion of the area where, of necessity, the water was shallow. There is no evidence of any sort that the water was deep; it will not suffice to assert that the presence of tree-trunks in the coal proves that there was an eddy here and that therefore the water was deep; that is merely an assertion that the fundamental assumptions are true. The presence of those tree-trunks in such wonderful abundance, can be utilized to prove that the doctrine is defective. But that is unimportant; if the conditions were as described in the Études, the water was shallow in the area now occupied by the Grande Couche. The middle bench of that coal bed is about 10 feet thick for a considerable distance, very clean, and consists so largely of prostrate tree trunks that it must represent a mass of transported vegetation which could not have been less than 150 feet thick. It is so free

from slaty admixture as to suggest that, during its formation, the streams brought into the area practically no inorganic material. It rests on the Banc des Roseaux, a sandy deposit literally crowded with stems and trunks, and extending apparently no farther than the coal in any direction. The purity of the coal shows that the whole mass was brought down at once, and it is at the head of the recess between the Bourrus and Colombier deltas—where neither it nor the sandy bed below should be.

A flood, so terrific as to sweep such a mass of vegetation from the little drainage area, could not be confined to the head waters of the Bourrus and Colombier; the other short streams between them would also be in flood, pouring their great contribution of water into the pond. There could not be any eddying; the whole surface of the water would be dashing with its load toward the outlet. If that were blocked, much of the deposit would be made along the southern border. But, even conceding that the trees were not deposited there, one must not forget that floods of the supposed violence are of brief duration and that floating wood remains very long time before becoming waterlogged. The surface movement would be steadily toward the outlet; there is no conceivable manner whereby the enormous mass of trees could be pushed against the current so as to be deposited at the head of the pond, where the water was too shallow to float the raft not less than 150 feet thick. But aside from this, the coal is not where it should be. According to the law of deposit on a deeply submerged delta cone, coal should be found crossing the cone in curved lines and it should thicken in the direction of the finer sediments. But there is no coal curving across the Bourrus delta; the coal of the Grande Couche disappears in the direction of finer sediments.

Conditions in the Decazeville basin bear no resemblance to those in the Commentry basin. The relation of the coal beds to old river courses and the variations in thickness are wholly different. The theory that coal beds were deposited on the slopes of submerged delta cones does not account for the conditions observed in those basins; Grand'Eury and Gruner found that theory inapplicable to

the Loire basin. Its author did not assert that it could be utilized to explain conditions in paralic areas, but he evidently expected to find support for it in those also. It is fully evident that it has no application whatever to the Appalachian basin, where the rocks were deposited in horizontal condition. Even now, they are almost horizontal in areas of many thousands of square miles within Ohio, West Virginia and Pennsylvania, where for long distances the dip is from one fourth to one half degree—and this dip is not original, for the region was affected by the Appalachian revolution and the beds were flexed. One nowhere finds any evidence of the submerged, steeply dipping beds of a delta; but the thousands of oil-well records show conformity throughout the Coal Measures column—aside from the variation due to local conditions or to widespread differential subsidence.

The term "Delta theory" is an unfortunate misnomer. "Delta," as ordinarily understood, designates not merely the submerged cone but also and chiefly the horizontal, alluvial deposits, and it at once suggests conditions observed in the lower reaches of great rivers, where the neptunian beds have very gentle slope. But this doctrine concerns only deposits made in small bodies of water by short torrential streams. The formation of a cone, such as the doctrine requires, would be possible only if the water were very deep and the bounding wall precipitous where the streams enter. There is no evidence that the conditions existed. No fault is known on the northerly side, but a limiting fault is indicated on the southerly side of the Commentry basin. There may have been important accumulations of water, at times, due to blocking of the exit or to depression along the fault, but such disturbances could have been of only brief duration. The conditions at Commentry resemble very much those observed along the Upper Rhone, and the writer is inclined to regard the "deltas" of the Bourrus and Colombier as alluvial fans.

Some of the "deltas" in the Decazeville basin have all the characteristics of alluvial fans and the deposits show distinctly the selective action of running water; but there are others which are not due to stream action. The great granite conglomerates, with huge

blocks encased in coarse to fine granitic sand, are merely disintegrated granite, the same as that which one sees at many localities between Montluçon and Decazeville. This is much like the great deposit underlying the Mesozoic coal area in Virginia, described by Shaler and Woodworth.[143] The writer could discover no evidence that a deep body of water occupied the Decazeville basin at any time, but there is abundant evidence that the water area was never extensive, except possibly toward the close of deposition.[135]

The doctrine of allochthony is not bound to the hypotheses which have been considered, for some of its defenders have no patience with either the Delta or the Barricade theory. The essential feature of the doctrine is, that vegetable matter growing on the land was removed by running water and deposited in water-basins, there to become coal; but there are individual differences in detail. Woodward, Scheuchzer, Conybeare, Buckland, Murchison, Fayol, de Lapparent, Renault, Ochsenius, Lemière and Stainier believe that the work was done by energetic floods; Grand'Eury and Sterzel see no proof of devastating floods, but appear to regard great rains and mild floods as sufficient; while de Jussieu, Buffon, Hutton, Faujas-St.-Fond, Naumann and Jukes do not concern themselves with the work of transference, but deal only with distribution after materials have reached the water-area. But for all, the principle of distribution by gravity holds an important place. One author puts the matter compactly. Coal plants grew on continents bordering great depressions, into which the meteoric agencies carried vegetable débris along with materials torn from the land by erosion. As calm was restored, the materials went to the bottom in well-defined order, determined by density; sandstone first, then the mur, then the coal and, finally, impalpable clays reached the bottom to form the roof.

Many authors appear to be convinced that all portions of a

[134] N. S. Shaler and J. B. Woodworth, "Geology of the Richmond Basin, Virginia," 19th Ann. Rep. U. S. Geol. Surv., 1899, Part II., Pl. XXI.

[135] J. J. Stevenson, "The Coal Basin of Commentry in Central France," *Ann. N. Y. Acad. Sci.*, Vol. XIX., 1910, pp. 161–204; "The Coal Basin of Decazeville, France," ibid., Vol. XX., 1910, pp. 243–294.

vertical section must have been formed after the same general fashion. Surprise is expressed because coal beds are believed by any one to have an origin different from that of the sterile beds enclosing them; the presence of marine deposits in a column is evidence that the whole column owes its origin to transported materials. But there seems to be little ground for any generalization of this kind. It can hardly be accepted as accurate for a single bed, though it has been so applied. Perhaps Fayol's statement is the best illustration. He had proved that sandstone and shale are composed of materials transported by running water and that the enclosed fragments of plants had also been transported; shales and sandstones, by increase of plant remains and decrease of inorganic materials, become carbonaceous and, in some cases, pass into coal beds; community of origin throughout is clear. But there is a wide gap here between premises and conclusion. The latter is possible, even probable in some cases, but it cannot be accepted as a generalization, for the contrary is a familiar condition in actual peat deposits, where one often finds all possible transitions from sand or clay, on the border, through sandy or clayey peat to the clean peat accumulating beyond. The general assertion, when applied to a succession of deposits, seems to be equally inexact. Alternations of peat with marine deposits are frequent on the coast of the German ocean and English channel, and some of those peats are continuous with living bogs farther inland. Peat in the Bermudas rests on marine limestone and underlies aeolian limestone. In the same region, one may see a living coral reef, formed on submerged aeolian limestone and now in process of burial under aeolian limestone. A forest in Alaska still remains *in situ*, though a great thickness of transported sands and gravels has accumulated around the dead trunks. On many coasts, forests, submerged for centuries, are still recognizable, though material from the land has almost buried them. Borings in deltas and in river plains show that within a vertical distance of 300 feet one may find land, freshwater and marine deposits.

Distribution of deposits by selective influence of gravity is a very alluring suggestion, especially to those who believe that deposits

can be made only in a considerable body of water—itself a conception which is in great need of proof. But one must concede that it involves many and serious difficulties in its application to small areas, such as the Commentry and Loire basins, and still greater difficulties when larger areas are considered; the more so when one remembers the proposition presented by some eminent men, that a bed of coal may be the product of a single flood.

Taking the Commentry basin as typical for small areas, one finds that coal accumulation began there only after not less than 500 meters of inorganic deposits had been laid down and a considerable part of the area had been converted into land. The two ponds, Pegauds and Ferrieres, were separated by the barren zone of Montassiégé, débris from the Bourrus torrent. The areas of those ponds were perhaps rather more than 2,000 and 1,000 acres respectively. The floods leading to formation of the great coal beds on the north shore of those ponds were extreme; trees were carried down and deposited with the sands in all directions, erect, inclined, prostrate and, in at least one instance, upside down. The vegetable cover was stripped from the drainage area and the whole mass was swept along narrow gorges through which the torrential streams flowed. This conception of the violence is not excessive; nothing less could do the work; for one must remember that the streams were still young, their gorges had been cut in granite and gneiss; the course must have been tortuous and the beds irregular, with shoals and rapids. When this vast mass of débris reached the water-basins, deep or shallow, they would be churned up by the flood's mad rush for the outlet, through which the water would pour with the force of a lake Bagne débâcle, carrying with it the finer and much of the coarser materials. There could be no selection under the influence of gravity. The Banc des Roseaux, dividing the Grande Couche, contains trees in great abundance, supposed to have been brought down by the streams; no selection was there, for the deposit is not along the main stream line of either Bourrus or Colombier, but in the supposed bay between the deltas. It might be suggested that the flood exercised its selective power before beginning the downward course.

In applying the doctrine to larger areas, defenders of allochthony find many illustrations which they regard as more than important. Much is said of timber rafts on great rivers, the masses of floating vegetation on the Amazon, Congo, Orinoco and other great streams, the rake at the outlet of lake Tanganika, the dredgings by A. Agassiz, the accumulation of drift wood on many coasts and the distributing power of currents. But it is not easy to discover what bearing any or all of these can have upon the formation of a coal bed with its orderly succession of floor coal and roof.

The timber composing the Atchafalaya raft was gathered from caving banks along more than 20,000 miles of river courses; very little of it was contributed by floods. Neither the Atchafalaya nor the Red river raft was a solid mass; each was in patches, separated by considerable spaces of open water. If they had sunk to the bottom, no coal bed would have been formed, there would have been only a mass of sediment enclosing logs. And this was the actual condition discovered, when the floating portion of the Red river raft was removed. But, in any event, the statements respecting the extent and character of those rafts, found in many publications, have been proved to be fabulous. If those statements had been true, if trees 60 feet high had grown on the Atchafalaya raft, those very statements should have restrained allochthonists from utilizing the rafts in their defense, since they go to show the immensely long time required to convert timber to the sinking condition and to show also the great amount of inorganic matter entangled in the rafts. Reference to descriptions[136] by competent observers will be sufficient for the reader. The same remarks apply to all accumulations of driftwood. As has been shown on earlier pages, the observations by uncritical voyagers were inexact; photographs prove that driftwood on coasts occurs in scattered fragments, occasionally collected into loose piles. On the shores of lakes or bays, the wind often drives considerable quantities into masses, upon which waves toss sand or silt. McConnell's detailed examination of driftwood deposits on Lake Athabasca made the conditions clear and showed how erroneous were the conclusions drawn from Richardson's description. Con-

[136] "Formation of Coal Beds," II., these PROCEEDINGS, Vol. L., pp. 548–551.

sidering the extent of area whence driftwood has been drawn, the quantity stranded on coasts is remarkably small. It has been gathered by great rivers of America and Asia to be distributed by currents, which have originated since the Carboniferous.

Conditions on the Amazon, Congo and other tropical rivers lend no countenance to the assertion that great sheets of floating vegetation might have been brought down by rivers into estuaries to aid in formation of coal beds. Those great streams, in time of flood, unquestionably carry matted vegetation in considerable quantity. Earlier pages of this work contain descriptions by travellers, which show little tendency to scientific accuracy, but suffice to prove that the material, thus transported, is far from insignificant. At the same time, granting that strangeness of the phenomenon did not lead the traveller to exaggeration and granting that the statements do not tell even half of the truth, the relevance of the occurrences may well be questioned. No reason has ever been presented to justify a suggestion that streams, such as have been named, could have existed as tributaries to estuaries, in which one now finds the Westphalia-Nord coal basins; nor is there any ground for supposing that if they had existed, they would have carried the imagined sheets of plant materials.

It is difficult to understand why the observations by A. Agassiz have been regarded as supporting allochthony, since they in no wise bear on the questions at issue. There was nothing novel about them except the localities. Every one knew that the muds of ponds and lakes contain twigs, leaves, pollen and spores as well as occasional larger fragments of wood. It was equally well known that the silts on river banks contain transported fragments of plants; that the Mississippi and the Orinoco deliver vast quantities of driftwood into the Gulf of Mexico and the Caribbean sea, and the devastating effects of West Indies hurricanes have been described by many writers. If the trawls had not brought up much plant material with the muds of the Caribbean and those off the California coast, the condition would have been inexplicable. But Agassiz found no evidence of a coal bed in process of formation, he found no evidence of sorting of materials through influence of gravity, he found no proof

of elective affinity inducing plant materials to flock by themselves. He did find mud containing much vegetable and other organic matter. His observations indicate only that much plant material carried into the sea does become waterlogged and does sink to the bottom; but they give no suggestion respecting formation of coal beds, although they certainly explain well some features of carbonaceous shale.

The doctrine of allochthony accounts satisfactorily for many phenomena observed in the coal deposits, such as the fragmentary remains of plants in the roof, the presence of drifted trees in sandstones, the occurrence of marine limestones and many others. But these are explicable quite as easily by autochthony, so that they need no further note at this point. Allochthony, as the writer understands it, offers no adequate explanation of the lamination in coal, which does not resemble that of sedimentation; it fails wholly to account for a structure such as that of the Pittsburgh coal bed, whose thin partings of mineral charcoal and mostly impalpable silt persist in an area of several thousand square miles; its assumption of distribution of sediments under influence of gravity fails when applied to the Appalachian basin, for there the coal, as in Commentry and in other areas disappears with decreasing coarseness of sediments; it affords no means of explaining the remarkable purity of some beds which yield coal of very high grade throughout continuous areas of 2,000 to 7,000 square miles.

The fundamental assumption of allochthony is that rain and floods can remove the vegetable cover, living or dead, from land areas and can convey it to a water basin, there to be deposited and to become coal. This conception seems to be without foundation in actual conditions and to be based upon study of erosive processes in unprotected or disintegrated rocks. The effects of running water on a cover of vegetation were examined in Part II. of this work. It remains only to present the matter synoptically with reference to statements made in defense of allochthony.

It is well to restate the opinions offered by prominent defenders of allochthony, that there may be no misapprehension. Bischof thought that in the earlier times the land was more densely forested than now and that the streams carried off a much greater quantity

of vegetable matter. Grand'Eury, seeing evidence only of quiet deposition, did not recognize the agency of violent floods; the vegetable debris underwent disintegration and decomposition on the land whence it was removed by rain and ordinary floods. There seems to be no positive assertion in any part of Fayol's work that the floods were of extreme violence, but the torrential character of the streams and their great carrying power are essential features of his explanations. De Lapparent stated the matter with clearness, when he asserted that, in the Central Plateau, vegetable masses descended *en bloc* and were deposited as localized coal beds; so that a single flood might make a coal bed of any dimensions. Renault conceived that as there was no ice cap at the poles, the rainfall was greater, the floods more violent and the quantity of transported vegetable materials much in excess of the present, because the surface was covered with a vegetable growth surpassing that now found in the tropics. Lemière thought of deep lakes or lagoons fronted by vast low-lying plains; the contributing area was between the levels of low and high water; it was swept clear of vegetation during floods; a mass of vegetation removed *en bloc* might present the appearance of formation *in situ;* during low water, the streams would bring in little aside from inorganic materials. For Stainier, the plants grew on the continent, whence they were swept into depressions along with inorganic materials, the mass being assorted by specific gravity; the *Stigmaria* being denser, sank into the underclay.

The flooding of vast lowland areas is not hypothetical; the writer, in Part II. of this work, has cited many authors to show that, in the Ganges, Yang-tse-kiang, Amazon, Zambesi, Mississippi and other extensive drainage areas, great floods are only too familiar features; that for long distances, at times hundreds of miles, the lowlands are covered to the depth of many feet in strips 40 to 100 miles wide; the depth in some cases being such that only the tops of the highest trees can be seen. The water for these floods comes at times from highlands far away and is not that from rainfall over the flooded region; at other times, the storms originating in distant highlands pass over the area before the flood reaches the plain; but the characteristics are practically the same in all cases. The flood

is highest in the upper reaches, where the stream is narrower, but decreases in height where the flood-plain becomes wide, unless accessions have been received from tributaries. Floods of this type do not sweep vegetation from the flood-plain. If one accepting the transport doctrine in full should read of conditions in the Mississippi area with its several floods each year, 40 to 60 feet deep in various parts of the lowland region—sometimes converting areas of 10,000 square miles into inland seas—he would expect to learn that that region is in great part a dreary waste, deprived of vegetation and uninhabitable. But not so; it is the home of millions of people; it contains many cities with 50,000 to 500,000 inhabitants; a great part, which has not been cleared for cultivation, is still heavily forested, covered with ancient trees; even the swampy areas, subject to flood from long before settlement by man, abound in the majestic *Taxodium.* These floods lift buildings from their foundations and carry them away; they injure farming land by leaving a deposit of silt or sand; they disturb property relations by undercutting the banks or by digging a new channel across the necks of horseshoe curves; but they usually are of brief duration and normal conditions return.

Transportation of vegetable materials by streams is no matter of hypothesis. Every stream carries on its surface twigs and leaves torn off by the wind; rivers carry great quantities of coarse and fine débris, increased in times of high water by trees and shrubs from caving banks; but the cover of vegetation remains practically uninjured in spite of all attacks. Agassiz, Kuntze, Humboldt, Wallace and other travellers in South America; Merrill, Frankenfield, Humphreys and Abbot as well as other observers in the Mississippi area; Livingstone, Cameron, Baker, Stanley and other travellers in Africa; Medlicott, Blanford and others in India, all tell the same story, as has been shown on earlier pages. The lowland flood rises slowly, it does not scour the surface, it does not destroy the forest growth, large or small, it does not disturb the peat deposits. Even when loaded with cakes of ice, it is powerless against standing trees, as has been observed many times on rivers in the eastern states. The high-level line of floods is ascertained by noting the silt rings on

tree trunks—a method employed in South America, Australia and on the Pacific coast for semi-torrential as well as for lowland floods. The overflow flood, that portion outside of the channel, moves slowly at the bottom and does not scour; instead, it deposits inorganic materials. If forced aside into a narrow space, it may cut a channel; but in that case it has ceased to be a flood and has become a local current. These are characteristics of lowland floods everywhere; the movements of water are governed by the same law throughout the world; there is no reason to suppose that other laws prevailed during earlier periods, to be repealed abruptly at the beginning of the Quaternary.

The floods of torrents can hardly be regarded as supporting the doctrine of allochthony. In some features they resemble those on lowlands, but in many ways the phenomena are different. Ordinarily, torrents flow in narrow valleys, more or less gorge-like with here and there a petty flood-plain, on which trees grow. Some large rivers, such as the Potomac, Monongahela and others rising in the Appalachian chain, are torrential during flood in the greater part of their length, but differ from the ordinary torrent in the width of their valleys and of the wooded flood-plains. In all, the rapidity of flow suffices to carry off the water, with, at most, trifling overflow of the plain, the chief change being in the channel which may be widened or deepened. At ordinary stages, torrents, in areas of consolidated rocks, transport very little mineral matter and the water is
the plain, the chief change being in the channel which may be
very great. But the coarse material is pushed along the bottom, except in extraordinary instances, and comparatively little is carried over to the flood-plain. The rushing water does insignificant injury to trees or plants on that plain, in spite of great speed, as was shown well during the great flood of the Potomac. One can see this for himself along mountain torrents, where trees grow to within a foot of the ordinary water line. There are many such torrents in the central plateau of France, whose fierce floods have done no more injury to trees on their rocky walls than is done to trees by the lowland floods of the Seine area; only fallen stems and other unattached

débris are gathered up to be mingled with inorganic débris from the channel-way.

But there are floods, caused by cloud-bursts at the heads of streams with rapid fall in narrow gorges, which are destructive throughout. Such floods, loaded with coarse and fine rock material, scour the little flood-plains, removing soil and trees alike, the latter to be deposited with the mass of mineral débris in any or all positions, vertical, prostrate, inclined or reversed; and with them would be rootless stems broken off from the cañon walls. The condition is wholly similar to that caused by the bursting of a dam, as in the Johnstown or the Lake Bagne disaster. A torrent flowing in a gorge of gneiss or granite, especially if it be so juvenile as those imagined by Fayol and de Lapparent, would be a succession of falls and rapids, over which trees could not be carried unless the depth of water was such as comes from a cloudburst. It is deserving of note in this connection that plant remains occur very rarely in the Siwalik conglomerates, which, as described by Medlicott, were brought down by the fierce torrents of the Himmalayan slope. The small quantity of vegetable materials in Coal Measures sandstones is a remarkable phenomenon, for sandstones certainly tell of greatly increased activity in the streams.

But it is evident from the statements by Fayol and de Lapparent as well as by several others who have been cited, that the supply of plant material comes not from immediate vicinity of the gorges but from the whole drainage area. The difficulties in the way of this suggestion are very serious. The upland region of Fayol and de Lapparent must have been covered with a forest, denser than any in the temperates and with an undergrowth like that of a tropical jungle. Renault goes farther and thinks the vegetation of those days more exuberant than that of the tropics at this time. This condition makes the asserted results impossible, so that the conception hardly deserves the exultant compliment by de Lapparent, that it is a triumph of common sense.

If the flood gates of heaven were opened and the flow of water concentrated on one spot so as to work underneath the vegetable cover, the whole surface would be stripped of soil and all else; but

there is no other conceivable set of conditions whereby the supposed cover of vegetation could be removed. The mass of more or less disintegrated and decomposed plant materials on the surface was very thick; rain falling on this would be absorbed and the material would be cemented. The roots of plants would resist movement of the water; those roots form a network which, under very unfavorable circumstances, suffices to check that movement; a handful of loose sandy clay on a sloping shelf in a railway cut is hardly diminished by a dashing shower or the accompanying rills, if only a bunch of grass have thrust its roots through it. How much greater would be the resistance of the dense vegetation, one can hardly conceive. It would be impossible for a flood to retain any force after encountering such a wall, even though the slope were somewhat steep and though the water had been ploughing the surface for some distance. The observations recorded by Marsh[137] make this sufficiently clear. Any one who has stood at the edge of a wooded river-bottom during time of high flood, knows that, no matter how the water rages outside, quiet reigns within that area and the overflow moves gently. Where vegetation is dense, no flood does damage. A flood can never gain speed in a rolling country covered with such vegetation as supposed by Renault and others; within the matt of plants it would be as powerless for injury as is a great mass of snow on a densely wooded slope. One cannot repeat too often or emphasize too strongly that running water does not strip off a vegetable cover, that floods do not uproot forests, do not tear away beds of peat. This has been shown in Part II. of this work. Be it understood there is no reference here to digging of a new channel-ways by débris-laden streams; or to such local accidents as disturbances of the vegetable cover by eddies around stumps or large bowlders in an open area; or even to bursting bogs. Such accidents affecting a few rods or even acres, are very important to the farmer whose pet meadow has been ruined, but they are without interest to one studying conditions within areas of many square miles or along flood lines, scores to hundreds of miles long.

Allochthony applies one set of phenomena, occurring under defi-

[137] "Formation of Coal Beds," II., these PROCEEDINGS, Vol. L., p. 531.

nite conditions to the explanation of another set of phenomena, which are impossible under those conditions. It is in constant conflict with what seem to be the established laws in nature. The true explanation of the formation of coal beds may be still unknown, and it may be the lot of chemists, geologists and palæontologists to follow many paths of investigation for many years before discovering the truth; but, to the writer, it appears certain that the path marked by allochthony ends in a *cul de sac,* walled with contradictions; and that farther investigation along that path will be fruitless; for allochthony magnifies the exceptional into the normal and endeavors so to explain away the normal that it may appear to be the exceptional.

Autochthony.

According to the doctrine of autochthony, the plants, yielding material for the coal, grew where the coal is now found; this is not to deny that some deposits were made of transported materials; that would be to deny the evidence of one's senses; but such deposits are of limited extent and have definite features, which distinguish them sharply from deposits made in the normal way.

Cannel and Boghead.

The peculiar structure of cannel compelled geologists to recognize that in origin it differed from the ordinary coals. Newberry in 1857 asserted that it is merely vegetable mud, composed of macerated cells, deposited in ponds within swamps; Dawson in 1866, J. Geikie in 1872, E. B. Andrews in 1873 and Davis in 1880 enforced this explanation by their observations. In 1880, J. P. Lesley,[128] correcting an erroneous reference to his opinions, enlarged the conception and anticipated much of what has been announced in later years. His words are

[128] J. P. Lesley, Sec. Geol. Surv. Penn., Preface to Rep. *H5*, 1880, p. xxii. "Cannel coal I regard as vegetable matter macerated in water, mixed with gelatinous water-plants and with the fine sedimentary clay which even the purest current-water always holds in suspension; and I ascribe the origin of petroleum in cannel, as I do the origin of the well-oil, to such water plants and to gelatinous water-animals."

Hutton and Fischer and Rust observed that resinous bodies, cell-like in character, are abundant in cannels and similar materials; von Gümbel in 1883 found in cannel a wonderful mass of disks and spores with flocky clay, macerated cells and algæ-like plants. Cannel and boghead are surprisingly like the Lebertorf of Purpesseln in East Prussia, which is a collection of parts of plants in a felt-like mass containing insects, leaves, separated cells and pollen grains, there being 1,000 of the last to each cubic centimeter. He felt compelled to believe that cannel, boghead and the Lebertorfs of Purpesseln and of the kurischen Haffs originated in similar manner; and he regarded them as closely related to the Plattekohle of Bohemia as well as to the Tula gas coal of Russia. He observed the algæ-like bodies in the Tasmanite of Van Diemans land. Früh's studies on peat appeared in 1883. He described the Lebertorf as a liver-brown gelatinous mass, consisting very largely of algæ, there being more than 60 species at one locality; he discovered that the algæ are of comparatively rare occurrence in true peat. Penhallow in 1892 found great numbers of amber-colored rod-shaped bodies in the felted mass of a Mesozoic cannel.

The results of studies by Bertrand and Renault[139] have been given in considerable detail on earlier pages. They examined the boghead of Autun in France and the Kerosene shale of New South Wales. Both contain the flocculent material observed by von Gümbel and Penhallow, in which are the algæ-like forms with pollen grains and vegetable débris. This, they regard as an ulmic jelly precipitated from the brown waters on which the fleurs d'eau floated. An infiltrated substance was observed at both localities, penetrating thalli of the algæ and, in the Kerosene shale, showing a fluidal structure. Some plants and parts of plants absorb it energetically and it penetrates the brown flocculent material or fundamental jelly. Bertrand's later studies were summed up in 1900, when he stated that these "charbons gelosiques" are accumulations of fresh-water algæ in a humic jelley, their fossilization being in the presence of "bitumen." Spores and pollen became fossilized but did not liquefy.

[139] "Formation of Coal Beds," I., these PROCEEDINGS, Vol. L., 1911, pp. 88–93.

They condensed bitumen energetically as did also the hard tissues of plants, which give glance coal. The fleurs d'eau descended in sheets with other accidental bodies, the speed of descent depending on the stage of water; if the water were low, the fundamental jelly would retard or prevent descent. Absolutely tranquil water was essential and the precipitation of ulmic matters by calcareous waters was constant. The "bitumen," absorbed by the various bodies, is regarded by Bertrand as a substance intervening wholly formed and coming from external sources. He suggests that it may have been in the water, but, in any event, he could find no evidence to show that it came from the decomposing plants.

The resemblance of these bodies to algæ was recognized by von Gümbel who saw more than one type, as did also Fischer and Rust, but they entertained enough doubt to prevent them from giving generic and specific titles to the forms. Some later students have felt compelled to dissent from Bertrand and Renault's conclusions respecting the algæ-like forms. Jeffrey[140] subjected the whole series of cannels and bogheads to microscopic analysis. By special treatment he succeeded in reducing the minerals to such condition that he could cut serial sections with the microtome; and in this way he made a great number of slides, giving opportunity for study not possessed by his predecessors. Jeffrey's results confirmed Renault's conclusion that the cannels are composed in great part of flattened spores from vascular cryptogams, which are shown better in American than in European cannels. According to Jeffrey, the bogheads of Kentucky, of Scotland and of Autun contain readily recognizable spores—the forms termed algæ by Bertrand and Renault being really spores of vascular cryptogams—and a similar conclusion is reached respecting the forms observed in the Kerosene shale. Jeffrey is convinced that the well-preserved individual elements in these minerals are spores and he thinks that cannel and boghead are alike in origin. The plates accompanying his memoir are elaborate.

Thiessen's[141] results have not been published and only a brief

[140] E. C. Jeffrey, "On the Nature of Some Supposed Algal Coals," *Proc. Amer. Acad. Sci.*, Vol. XLVI., 1910, pp. 273–290.

[141] R. Thiessen, "Plant Remains Composing Coal," *Science*, N. S., Vol. XXXIII., 1911, pp. 551, 552.

abstract of his preliminary announcement has appeared. The cannels studied by him are composed almost wholly of spore-exines with resins and cuticles in limited quantity. The so-called binding material in the intestices is distinctly of two substances, one, more or less homogeneous and colloidal; the other, more or less granular, the fragmentary residue of spore-exines. He rejects the algal theory of Bertrand and Renault as well as the sapropelic theory of Potonié, both being undemonstrable. The so-called algæ are not algæ, all forms but one having been proved to be exines of spores, either of Pteridophytes or Cycadofilicates or of both. A gelosic substance such as is called for by the theory is wholly absent.

The exact nature of these bodies, though of extreme interest from the botanist's standpoint, is of subordinate interest here. The important fact seems to be that while these bodies are comparatively rare in ordinary coals, they are predominating constituents of cannel and boghead, thus indicating a different mode of formation. One must bear in mind also, that animal remains are present abundantly in many cannels.

The brown fundamental matter of the cannels and bogheads is apparently the same as that which forms the basis of ordinary coal, and it is supposed by Bertrand and Renault to be a precipitate from the brown waters of swamp-pools, the precipitant being lime. Such brown waters are widely distributed especially in tropical regions Samples of such water, obtained by Marcano in South America, were studied by Muntz[142] who discovered only a trace of lime in the dark water, which contains 0.028 gramme of organic matter per liter, yet has an acid reaction. The colorless waters are distinctly hard. The authors conclude that the acids were preserved in spite of aeration, because nitrification and consequent oxidation could not take place. When mingled with hard waters, the acids combine with the lime, nitrification begins and destruction of carbonaceous matter proceeds rapidly under influence of high temperature. The quantity of organic acids is small, even when the color of the water

[142] A. Muntz and V. Marcano, "Sur les eaux noires des régions équatoriales," *C. R.*, Vol. 107, 1888, pp. 908, 909.

is intense. Klement[143] found so little in the almost ink-black waters of Willebroeck that the material could not be investigated thoroughly. He observes that the brown waters of Gouda become decolorized very quickly in presence of pulverized calcite.

Humic and ulmic acids are certainly precipitated by lime; but one may not be regarded as hypercritical if he suggest that this can have very little to do with the supposed precipitation of ulmic matters in the ponds or stagnant waters of swamps. The deposit was laid down in water with undisturbed surface; that would be a stagnant pool, which could be filled only by rainfall or by seepage through the peat. But the seepage water, however rich it might be in lime at its entrance, would lose all while percolating through the peat, as organic acids would take it up; if, in course of time, an excess should exist and should reach the pool, the lime would find no organic acids there, as the bog itself would contain only the insoluble calcium compounds which could not be leached out in appreciable quantity. The condition would be the same, if the pond were fed by a stream meandering sluggishly through the swamp—no other would be possible under the supposed conditions. If the precipitation were a constant process and due to presence of lime, the precipitate should present abundant evidence, for there is no reason to suppose that the lime would be removed at any later time; the precipitation was not merely constant, but also so rapid that a thick deposit of boghead might accumulate in a single season. Everything, under such conditions, would be sealed up quickly. But analyses give no support to this conception of the origin, for lime is an unimportant constituent of bogheads. Liversidge[144] analyzed Kerosene shale from Greta and from Joadja creek in New South Wales. That from Greta contains about 28 per cent. of fixed carbon and nearly 16 per cent. of ash; but of the latter only 1.438 per cent. is lime. The mineral from Joadja creek has almost 16 per cent. of fixed carbon and 9 per cent. of ash; but of the latter only 0.3 per

[143] C. Klement, "Les puits artésiens de Willebroeck," *Bull. Soc. Belge de Géol.*, Vol. III., 1889, Mem. pp. 259–262.

[144] A. Liversidge, "Descriptions of the Minerals of New South Wales," Dept. of Mines, Sydney, 1882, pp. 162–164.

cent. is lime: no relation exists between the quantity of lime and that of fixed carbon or volatile. If one take the Joadja shale as containing only 10 per cent. of fundamental brown material, the condition remains, as the lime is but 0.027 per cent. of the whole, clearly insufficient for precipitation of the organic acids.

The supply of organic acids must have been very great in order that constant precipitation might be maintained, especially such abundant precipitation as to give several inches of fundamental jelly in the course of a single season—the water being stagnant. Everywhere, the brown waters, even when almost black, contain very little organic matter in solution, one part in 20,000 sufficing to give marked coloration and an acid reaction. The coffee-brown or greenish black waters of South America, according to Humboldt, are preferred to all others for drinking, being limpid and of agreeable flavor. Coville[145] has stated that water from the "juniper area" of the Dismal Swamp, with the color of tea, was the favorite source of supply for vessels departing on long voyages. This is a typical locality in the heart of the swamp; the water is acid in reaction and the flora is of the acid-resisting type, consisting of *Chamæcyparis,* alders and heathers. There seems to be no reason for supposing that, during Carboniferous times, the stagnant waters of swamps approached saturation with organic acids.

The suggestion that the "bitumen" is of extraneous origin, that it intervened fully formed, that it may have been in the water, is sufficiently perplexing. Bertrand finds no evidence that it was derived from the decomposing mass. It fills shrinkage cracks in the fundamental matter and it seems to have penetrated some tissues more readily than others—a condition which, for Bertrand, explains some differences in coals; glance, composed of barks and cuticles, absorbed much, but tissues in matt absorbed little. The algæ-like bodies had notable capacity for absorbing this bitumen. Renault[146] has expressed an objection, which, no doubt, presented itself to

[145] F. V. Coville, "The Recent Excursion into the Dismal Swamp," *Science,* N. S., Vol. XXXVIII., 1911, pp. 871, 872.

[146] B. Renault, "Études sur le terrain houiller de Commentry; Flore fossile," Livr. 2, 1890, pp. 687, 688, 701, 702.

many readers of Bertrand's memoirs. The invading bitumen must have possessed extreme fluidity, as it was injected into all parts of the vegetable débris, passing even through the walls of cellules; but that fluidity would have led to complete penetration of the sandstones and shales in which one finds the often widely isolated coaled plants; but no evidence of that penetration is seen. He objects also that if the penetration had been made into tissues, the coal should have the appearance of a compact resinous mass; but the coaled wood is porous and he found no "bitumen" in cells and vessels.

The term "bitumen," as employed by Bertrand, is extremely vague and its actual signification cannot be gathered from any of his writings. A reference to the La Brea (Trinidad) conditions suggests that a petroleum is the supposed source. This area was studied by Cunningham-Craig,[147] who states that the Rio Blanco sandstone has so much petroleum that, though tide-washed, it has 15 to 18 per cent. of sticky oil or soft pitch on the surface, and it constantly exudes similar material into the Pitch Lake. The existence of such asphaltic matter would be recognizable in the rock after any period, no matter how long—one finds asphalts in Carboniferous limestones and sandstones. The glance coal in sandstones is caking, rich in bitumen. The objection, however, is not insuperable. A light-colored oil with paraffin base might leave no notable trace in the sandstone. At the same time, one must bear in mind that paraffins do not change, and that the great supply is from Palæozoic rocks. If they penetrated the rocks and the tissues, it is certainly strange that certain solvents extract so little from coal or cannel or boghead. Destructive distillation, under similar conditions, obtains rather abundantly from coals some substances which are almost absent from petroleums.

But one cannot resist the query, Why go outside of the decomposing mass for the source of "bitumen"? If a source can be found in that mass, there seems to be no good reason for searching after recondite sources. Coals, even those of Carboniferous age,

[147] E. H. Cunningham-Craig, "Preliminary Report on Guapo and La Brea District," Council Paper, No. 30, 1906, pp. 3, 4.

very often contain macroscopical masses of resins, which, in color, are very similar to the material revealed by the microscope. Palæobotanists have discovered in ferns certain organs closely resembling those which, in modern ferns, secrete resins and there appears to be good reason for supposing that Sigillarids yielded much resinous material. The gums, resins and other substances, originally soluble or rendered soluble by microörganisms, would be deposited in tissues and crevices. The feature is familiar in recent bogs and those of the Quaternary, where the fluidal ulmic and other allied substances fill not only cavities in the bogs but also in the underlying bed.

The formation of the cannels and bogheads would seem to be explained sufficiently by the earlier conception, which has the double merit of simplicity and of accordance with conditions known to exist. The minerals consist of vegetable muds with contribution more or less important by plants and water animals. The great abundance of spores and pollen grains is paralleled in modern times by showers of pollen, the "sulphur showers" in wide areas; fresh-water algæ abound in pools of actual swamps—possibly their existence in Coal Measures times is still problematical. Modern sapropelic deposits bear, in many ways, very striking resemblance to cannels and bogheads, though certainly there is no evidence of a "bitumen" infiltration. But the hypothesis of extraneous origin of the "bitumen" seems to be unnecessary, so that, to be accepted, it should be supported by incontestable evidence. Lesquereeux[148] cites Ziegmann's analysis of an impure peat, which yielded 6.2 per cent. of wax, 0.4 per cent. of resin, and 9 per cent. of "bitumen." It is sufficiently well known that peat, subjected to destructive distillation, gives ample evidence of containing bituminous matter. Thenius, cited by Davis,[149] has shown that air-dried peat yields 6.39 per cent. of petroleum, lubricating oil and paraffin wax, besides 40 per cent. of tar oil. The dried tar yields 54 per cent. of the same substances and a notable quantity of ammonium sulphate. The

[148] L. Lesquereux, Sec. Geol. Surv. Penn., Rep. for 1885, p. 117.

[149] C. A. Davis, "The Uses of Peat," U. S. Bur. of Mines, Bull. 16, 1911, p. 136.

Ziegler process for securing these substances from peat has been tested on the commercial scale, with results approximating those obtained by Thenius.

Autochthonists claim that their doctrine is in accord with what is known of nature's processes and that its fundamental assumptions can be verified by observation. They recognize that in some respects, modern differ from ancient conditions. The distribution of heat on the earth's surface is clearly unlike that during the Carboniferous; the dominant plants of modern forests did not exist at that time. But the Carboniferous plants have relatives in the modern flora; the chemical laws governing decay of plants have remained the same throughout, as proved by a continuous record; the erosive action of running water has shown no change in method; the laws controlling the deposit of transported materials have remained unaltered from the earliest times. There have been great changes in animal and vegetable life; many forms have become fitted to new habitats; but such modifications are not unknown in modern times and they are not regarded as strange.

The modern peat bog is taken to be the analogue of the ancient coal bed. The vegetation is dissimilar, but that is unimportant. Land-plant material, be it of one sort or another, gives peat under the proper conditions. The final substance is practically the same in the cedar swamps of New Jersey, the cypress swamps of the southern states, the swamps of Scandinavia and in the buried swamps of the southern states, the swamps of Scandinavia and in the buried swamps of the Ganges, western India or the Mississippi; and, in all of those, it is the same as that in the great tropical swamps of Florida, Demarara and Sumatra, where it is derived from wholly different types of plants. Everywhere, the final result of decomposition is the same; the plant material is converted into a mass of organic acids and salts, enclosing large or small woody fragments of resistant composition. The difference in plants does not affect the matter under consideration; Carboniferous plants were converted into peat when exposed to the proper condition, just

as are modern plants, the same organic materials being common to them both.

The vast extent of some coal fields is urged as a vital objection to autochthony, because there are no delta-plains so great as the larger coal fields of America or China. But this is not correct. The Ganges-Indus flood plain area, like that of the Yang-tse-kiang, is as great as the Appalachian basin and each has, in a considerable part of its extent, conditions favoring accumulation of peat. Too many writers commit the error of confounding extent of coal field with extent of coal bed, and they refuse to believe that peat could accumulate synchronously throughout the vast areas. Though in no wise enamoured with modern causes, they appeal to them quickly and cite the limited extent of modern peat bogs, none of which resembles the Appalachian coal basin. But these writers forget or do not know that coal was never accumulating at any one time throughout a great field. Even at the time of the Pittsburgh coal bed, with its probable area of more than 12,000 square miles, there was not synchronous accumulation. During the earlier part of that bed's history, as shown on an earlier page, coal was forming in less than one third of the area; and during the later portion there was no accumulation in perhaps half the area. So with other beds; coal accumulated at separated localities, a few square miles or hundreds of square miles in extent, sometimes near together but at others far apart. During most of the time, conditions were unfavorable to coal accumulation in probably by far the greater part of the more extensive basins. One has to consider not vast sheets of coal, but local deposits. The condition, most probably, was that now seen in Holland, Belgium, northern France and northern Germany, where the peat deposits are in separated areas, large and small; but they are contemporaneous and mark a definite horizon. The important continuous area of Holland, Belgium and northern France, now largely buried, is nearly as large as that on which any bench of the Pittsburgh seems to have accumulated; and the thickness in some places is important. The Everglades of Florida is almost as extensive and is only one of the many swamps in Florida, where the distribution is very like that at some coal horizons in the

Appalachian basin. The thickness of certain coal beds has been regarded as weighing heavily against autochthony. But the modern peat bogs, which have been studied in detail, are youthful, of only post-glacial origin. Possibly in course of time there may be at many places peat deposits of immense thickness like those in some portions of the Alaska tundra; but it is more probable that no deposit will excel the average coal bed; reclamation of marsh land has checked peat accumulation in much of Germany and is likely to do it throughout the civilized world.

The earlier writers studied mostly the treeless moors; but many features of coal beds, wanting in those, are reproduced in the Waldmoors or forested swamps, which are familiar in much of northern Europe and in the United States. In all probability they are of much greater extent on the broad plains of the Amazon and Orinoco, where, however, they have been studied only as forested swamps and not as producers of peat. Kuntze has shown that similar areas of vast extent in the Paraguayan region are genuine Waldmoors. The prevailing flora of such swamps in the temperates consists of conifers, heathers, sedges, with ferns and, usually as late arrivals certain mosses. These plants are in a habitat resembling that in which the Coal Measures plants are supposed to have lived, so that there should be important features in common, if the doctrine of autochthonous origin be true—for that asserts that the older flora grew in areas covered with decomposing vegetable materials.

The swamp flora of modern times consists very largely of plants with marked xerophytic or drought-resisting features; similar characteristics have been recognized in the Coal Measures flora, as well as in those of some later coal-making times. The facts that some plants living in swamps are found elsewhere, flourishing on arid or semi-arid soils, has led to the suggestion that they may be only interlopers. Henslow[150] has conceived that the xerophytic features of *Stigmaria* and *Lepidodendron* could have been acquired by living

[150] G. Henslow, "On the Xerophytic Characters of Certain Coal Plants, and a Suggested Origin of Coal Beds," *Quart. Journ. Geol. Soc.*, Vol. LXIII., 1907, p. 283.

long on dry ground, and that they could have been retained even after the forms had migrated to a swamp. Seward and Hill,[151] on the other hand, recognized indications in the structure that the conditions of growth required development of characteristics associated with the xerophytic habit.

The readiness with which certain types of plants accommodate themselves to the extreme dampness of swamps or to the aridity of sands has been, long time, subject of investigation. Davis[152] says that swamp plants growing at the water-level are drought-resisting; their leaves are contracted, have dense cuticle and are often coated with waxy or resinous materials. The condition against which they are protected exists in swamps as well as in dry soils. Peat, though holding much water, parts with it reluctantly; even after the centrifugal test, the retained water equals 142 per cent. of the weight of the dried peat, and the material appears to be merely damp. Under similar conditions the retained water in sand is but 2 to 4 per cent. There is physiological dryness in peat; the water is ample but not available.

Coville[153] has shown that another agency is important. He recognizes fully the fact of physiological dryness, but he regards another agency as of equal or in some cases of much greater importance. The blueberry grows luxuriantly in swamps, but equally well in the sandy soil of pine and oak woods on the Coastal plain and in the spruce woods of the White mountain slopes. The factor determining distribution of this plant is acidity, it cannot thrive if the soil be alkaline or neutral. The surface in the pine and oak woods, as in the spruce forests, is covered with a litter of decomposing twigs and leaves, whence organic acids are carried to supply the plant's needs. The rootlets are without the fibrous appendages, which

[151] A. C. Seward and A. W. Hill, "On the Structure and Affinities of a Lepidodendroid Stem," *Trans. Roy. Phys. Soc. Edin.*, Vol. XXXIX., 1900, p. 928.

[152] C. A. Davis, cited in "Formation of Coal Beds," these PROCEEDINGS, Vol. L., 1911, p. 601.

[153] F. V. Coville, "Experiments in Blueberry Culture," Bur. Pl. Ind., Bull. 193, 1900; "The Formation of Leafmold," *Journ. Wash. Acad. Sci.*, Vol. III., 1913, pp. 87–89.

characterize ordinary upland plants, so that the absorbing surface is reduced, while the protected leaves prevent rapid loss by evaporation. The rootlets contain abundantly a mycorrhizal fungus, which fills many cells and forms a network outside on the cell wall. Similar fungi were discovered by Miss Ternetz in rootlets of the cranberry and other swamp plants. Coville finds them in most of the acid-loving plants, such as the laurel, birch, chestnut, conifers, oaks, club mosses, ferns, orchids, and thinks probable that they convert the unavailable nitrogen of acid, peaty soils into available nitrogen, so as to provide proper nutriment to the plants.

Fungi, myriapods and insect larvæ are efficient in hastening decomposition. Coville says that myriapods are almost incredibly abundant in the very acid laurel (*Kalmia*) peat. Renault[154] presented to the geological Congress at Paris a synopsis of his great work on the "Microorganismes des combustibles fossiles," in which he indicated the work performed by lower types of life. Study of the Grand'Croix flints proved that micrococci and bacilli abound in that petrified peat as they do in modern peats; he found them abundant in bogheads, cannels, lignite and coal. Mycelia of minute champignons are present in the macrospores of Kentucky cannels as well as in wood fragments of coal beds. The close resemblance to peat conditions led Renault to the conclusion that the plant materials were infected during sojourn in swamps before being swept away by floods, which he believes were extremely violent during Palæozoic time.

Conditions during Coal Measures Time were Favorable to Accumulation of Peat.

Assuming that the writer's conclusions[155] presented on an earlier page are approximately correct, one must regard the Appalachian basin, at the close of the Pottsville, as in great part an irregular plain, raised not far above sea-level and liable to flooding by many

[154] B. Renault, "Du rôle de quelques bacteriacées fossiles au point de vue géologique," *C. R. VIIIe Cong. Géol. Int.*, 1901, pp. 646–663.

[155] "Formation of Coal Beds," III., these Proceedings, Vol. LI., 1912, pp. 552, 553.

rapid streams issuing from the Appalachians at the east and the Canadian highlands at the north. The sluggish drainage was rendered more uncertain by irregular subsidence, by formation of gentle plications as well as by local elevation or subsidence in more or less extensive areas. Almost the whole basin was land at the beginning of the Pennsylvanian, as appears from the unconformity between that and the underlying Mississippian, which is marked by an eroded surface in all parts of the area, and by the absence of the Pocahontas and New River beds from the northern portion, except in part of the anthracite area. The gradual northward advance of the Beaver deposits evidences the slow and frequently halted subsidence. The conditions were wholly similar in Indiana and Illinois, west from Cincinnatia, and they are equally distinct in Iowa and Missouri, west from the Mississippi river. In all this vast area of perhaps half a million square miles, one finds the unconformity between Mississippian and Pennsylvanian marked by extended erosion, and the first beds of coal, in any district, are irregular, occupying more or less isolated basins in the eroded surface.

The relations of erect tree stems are important in this connection. Much energy has been expended in the effort to prove that transported trees can be deposited in vertical position; but all that energy has been wasted, for no one, familiar with the matter, ever had any doubts respecting the matter. The possibility could not be disputed; the doctrine of chances converted it into a probability and the existence of snags in the Mississippi river made it a certainty.

All such discussion is foreign to the subject and tends to divert attention from the only point at issue, which is, Are these particular stems *in situ* or not? Each occurrence stands alone and it must be considered apart from all the rest.

Erect stems have been observed in all coal fields and often in such relations that not merely unscientific observers but also trained geologists feel compelled to recognize that they are *in loco natali;* Jukes, when he saw the Parkfield stumps, admitted, though somewhat grudgingly, that the trees certainly looked as though they had grown there and that perhaps they had. The observations by Beckett, Ick, Darwin, Goeppert, Sorby, Barrois and others, recorded in earlier

pages, describe trees as clearly *in situ* as are those of Senftenberg, described by Potonié, or the stumps in cedar swamps of New Jersey or the cypress swamps of Louisiana. One is amazed at the manner in which the evidence is received, for not infrequently there is an implication that all may be mere assumption, that possibly other explanations may be found, since no one saw the trees growing. It is an assumption, as is almost everything in the reasoning of everyday life. The writer has seen many extensive areas of cleared land on which the stumps remained; he had not seen the forest in existence, but the relations of the stumps convinced him that they were *in loco natali*. Buried or submerged forests are commonplace now.

The argument in favor of *in situ* origin is based on clear-cut observation. The branches of *Stigmaria* are interlaced in such complex fashion that the most ingenious efforts have failed to explain away the phenomenon, and allochthonists have found themselves compelled to resort to the remarkable suggestions of débâcles and transport *en bloc;* but those were impossible amid topographical conditions such as, according to both allochthonists and autochthonists, must have existed in the Coal Measures areas. It is absolutely certain that no such disturbances accompanied the deposition of the rocks holding the tree stumps, for every feature indicates gentle action; the rhizomas are spread out in normal condition and retain their slightly attached appendages, while the rock itself is the same in all features as it is elsewhere. In many localities, such as those described by Schmitz, Ick, Lesquereux and others in the Coal Measures, Potonié, Darwin and others in the Tertiary, the spaces between the trees are such as are found in forest growth. In some cases, such as those mentioned by Goeppert, Dawson, Grand'Eury and others, successive growths on the same site are recorded, roots of the newer generation descending amid the stems of their predecessors. Not rarely, the roots pierce impressions of leaves previously buried in the soil. At times, prostrate stems are abundant in the intervals between erect stems and frequently the former outnumber the latter; just as one sees on the surface of forested swamps along the Atlantic coast and in the southern states. In not a few cases, the debris of leaves and twigs accumulated about the bases

of the trees, becoming a thin coal bed overlying the roots and extending to a considerable distance. This too is a familiar condition in modern times. "Upland peat," as Coville has termed it, sometimes accumulates to notable thickness in conifer and oak forests: he reports a thickness of 5 feet in some areas. The writer knows only too well that such peat accumulates to a thickness of more than 3 feet in the forests of gigantic firs within New Mexico; on more than one occasion, his camp narrowly escaped destruction because the peaty material had not been removed to the bottom before a fire was lighted.

Erect stems in many cases are cut off abruptly at top or bottom, as abruptly as though they had been sawed off. For this condition, which occurs so often in the roof of coal mines, there is no explanation aside from growth *in situ*. The absence of roots to sawed off stems in the roof, and of crowns to sawed off stems in the mur can be due only to slipping of the coal, which destroyed the original continuity.

The great number of erect stems discovered in the narrow exposures of mines and on the still more limited space of natural outcrops renders wholly reasonable the suggestion that, if coal were mined by stripping, fossil forests would be found abundantly in all fields, as Binney long ago suggested for the Lancashire region. The stems, which have been found, are associated in many cases with ripple-marked sandstones, the ripples at times resembling the complicated forms characterizing dunes or loose sand. Altogether, the evidence showing that the trees, under consideration, grew where they are found, is in every respect as conclusive as is the evidence that the logs between Cape Malagash and Wallace Harbor, described by Dawson,[156] are a petrified raft of driftwood, or that the irregularly distributed battered timber found in sandstones is not a growth in place. The reasoning is the same in both cases, an application of knowledge gained by actual observation to explain conditions where actual observation of the process is impossible.

While the existence of great numbers of trees *in situ*, so dis-

[156] J. W. Dawson, "Some Fossils found in the Coal Formation of Nova Scotia," *Quart. Journ. Geol. Soc.*, Vol. II., 1846, pp. 132–136.

tributed as to suggest strongly that they belonged to forests, may have no direct bearing on the formation of coal beds, it has an extremely important indirect bearing. It is part of the proof that the region was a land area, covered more or less with vegetation. The other elements of the proof have been set forth with ample detail in Part III. They are, the extraordinary horizontality of the strata in many thousands of square miles, where the disturbing forces have not acted, showing marked resemblance to conditions on the Siberian steppe, described by Belt, or to those on the Gangetic plains, described by Blanford; the absence of plant remains in sandstones and shales in great areas; the presence of coal and shale pebbles in many deposits; the gradation in size of pebbles, indicating rehandling by streams; the extreme freedom from fine material along definite lines of coarse rocks, distinct evidence of river selection; the buried valleys, scores to hundreds of miles long; the gullied coal beds; the widely extended sub-aerial erosions: the vast deposits of fine shales, proof of long sub-aerial exposure of the rocks, whence they were derived; the shallow water character of the localized marine limestones, which occupy definite areas, resembling estuaries extending into valleys; the ripple-marks, suncracks and footprints, observed at many horizons. Some of these features, if they existed alone, might be explained in other ways; but they do not occur alone. They must be considered as a whole. The conditions were such as to favor the accumulation of peat; the coal beds must have accumulated under practically sub-aerial conditions—unless one accept a flexibility of the earth's crust, many times greater than that which some allochthonists imagine is demanded by autochthonists.

The Peat Deposits Resemble Coal Beds.

Grand'Eury says that in the coal the plants have been broken up and the parts scattered; fruits and leaves are separate from their stems; layers of bark have been displaced; the interior portions of stems have disappeared and only the flattened cortex remains; woody parts have been dispersed as fusain; stems are split and torn; *Cordaites* leaves are imperfect; everything, bark or leaf, is

fragmentary; a great part of the tissues was transformed into a vegetable pulp, which makes up most of certain coal beds. Long ago Lesquereux described mature peat in very similar terms, the fragmentary materials being embedded in an amorphous material, consisting of organic acids and their salts. Von Gümbel's description is much the same; the amorphous material, much of which was originally flocculent, is his Carbonhumin, which binds together the plant fragments and the often abundant mineral charcoal, which he terms, Torffaserkohle. The cementing material, soluble in the bog, becomes insoluble on drying. Grand-Eury's description of coal applies equally to matured peat, especially well to that of the American cypress swamps. It is thoroughly applicable to the "coal balls" as well as to the Grand'Croix flints, all of which are regarded by investigators as petrified peat.

In one respect, however, the description does not apply to many peat deposits. Coal often consists largely of flattened stems, the interior having disappeared. On preceding pages, the presence of prostrate stems and erect stumps has been mentioned as characteristic of old or new Waldmoors in all parts of the world. According to Harper, such stems and stumps are so abundant in many Florida swamps as to make the peat commercially worthless; Cook says that in the New Jersey swamps stems of white cedar are so numerous that one has difficulty in thrusting a sounding rod through the mass. Similar crowding of stems appears to be a familiar feature in the deposits of northern Europe, according to all observers from De Luc to the present. In very large part, the wood is fairly well preserved; the Irish bog oak and the New Jersey white cedar are utilized by cabinet-makers. Grand'Eury's description affords the explanation. There was little woody material in most of the Carboniferous trees; there is much in the conifers and oaks of modern swamps. But woods of other types do occur in flattened condition within peat; von Gümbel found them at the depth of only one meter, so that the collapse was not due to pressure. Früh made the same observation in the great Digenmoor of the Bavarian highland; the late-Quaternary Schieferkohle contains flattened stems of harder woods—and here too the deformation is not due to pressure, for cones, not de-

formed, lie alongside of the flattened stems. Erect stumps are of comparatively rare occurrence in the coal, but they abound in Tertiary and Quaternary deposits. Evidently, cellulose predominated in the older forms as lignin or woody tissue predominates in the newer. As Andersson[157] says, if the cell walls of all plants had consisted of pure cellulose, we probably should have found scarcely a trace of the plant world which once existed upon the earth.

Peat is laminated but not in all cases like coal, for in the latter, the lamination is due very often to flattened stems. The existence of well-preserved woody stems in many swamps obscures the lamination. But Lesquereux long ago recognized the layer-like structure of new peat, where the thickness of layers is not far from an inch, while in the mature peat it is not more than an eighth. Von Gümbel ascertained that compression makes the lamination of even sphagnum peat distinct.

Peat beds have definite benches like coal beds. Lesquereux says that in some bogs the ash is different in color. Such benches are as well marked in peat deposits of northern Europe as in any coal bed and they are equally well marked in the Schieferkohle of Switzerland, so that the history of each bench is clear. The passage from one to another is abrupt, as appears from sections given in Part II. There are, very often, distinct partings, consisting of a crust formed during periods of dryness, when growth of peat is checked and oxidation succeeds; this crust persists after growth has been resumed. Its character is very similar to that of the thin partings in the Pittsburgh coal bed, which consist of mineral charcoal with mostly impalpable inorganic matter, such as would remain after oxidation of vegetable substance. Explanation of those partings in this way seems to very simple and not far-fetched; lowering of the water-level only a few inches would suffice. The period during which that bed accumulated was one of irregular and more or less differential subsidence.

On a preceding page, it was shown that the ash in coal is from less than 1 per cent. to any per cent., the passage from coal to carbona-

[157] G. Andersson, "Studier öfver Finlands Torfmossar och fossila Kvartärflora," *Bull. Com. Géol. de Finlande*, No. 8, 1898, p. 191.

ceous shale being continuous, from the chemist's point of view. So with peat, for one may find clean peat with little ash passing gradually into ordinary mud within a mile or less. Coal at times has very much less ash than was contained in the plants whence it was derived; the same is true of peat, which, as a commercial product, has from 1 to 20 per cent. But sphagnum has from 3 to 4 per cent., yet Vohl analyzed a sphagnum peat which contained only 1.25 per cent. of ash.

Coal beds are buried deeply under detrital deposits; but those deposits were laid down, one at a time. Peat beds are of late-Quaternary or Recent age; opportunity for deep burial has come to few of them. But buried bogs are a familiar phenomenon and in some cases the cover is thick. At one locality in Ohio, a bed, 15 to 20 feet thick, underlies 90 feet of sands and gravels; in Indiana, one bed, 2 to 20 feet thick, has been found underlying a considerable area at a depth of 60 to 120 feet. The buried peats of Scotland, France, Germany, Holland, Switzerland, equally with the buried cypress swamps of the Mississippi region and the great buried swamp of the Ganges area, all afford proof that it is not the necessary fate of peat bogs, *in situ*, to be destroyed by oxidation.

The extent of modern peat deposits compares very favorably with that of coal beds; that, extending across Belgium from Holland into France, equals the extent of the Pittsburgh coal bed as it exists to-day. The upper peat bed of the Gangetic plain seems to have been proved in an area of nearly 2,800 miles, exceeding that of any American coal bed except the Pittsburgh and two in the Middle Pottsville. The Alaskan tundra has much greater continuous areas and at some localities the thickness is very great.

Coal beds frequently divide and in some cases the divisions reunite. Peat deposits do the same, as Lorie's records show. True, the divergence of peat benches is not so remarkable as that observed in some coal beds but otherwise the condition is the same; at times, the origin of other features is suggested. The irregular subsidence of the New Madrid region on the Mississippi affected an area of rather more than 2,000 square miles; when that depressed region has been filled up by silts and overspread by a new swamp, division and re-union will be as distinct as it is in the Mammoth coal bed.

Peat deposits rest as do coal beds on sandstone, shale, clay or limestone and the limestone may be either fresh water or marine. Like coal beds they underlie a roof of any sort and at times they are intercalations in marine calcareous shales. The association with marine beds is clearly no evidence of deep water or of flexibility in the earth's crust.

In Conclusion.

The coal beds and the associated rocks are of land origin; the detrital deposits are those made by flooding waters on wide-spreading plains; the coal beds, in all essential features, bear remarkable resemblance to peat deposits, sometimes to the treeless moor, more frequently to the Waldmoor.

But many matters still await explanation, among them some which the writer hoped to explain as result of this study. And they are likely to wait long. No extensive coal field has been studied closely; in spite of the imposing array of skeleton sections, there is an astounding lack of detail respecting many matters which appear to have no important bearing on commerce. Until the topography and geography of the Coal Measures land have been worked out, geologists must be content merely with probabilities concerning the remarkable bifurcation of some coal beds, the variations in subordinate intervals between two approximately parallel coal beds, the presence of huge blocks of transported rock in coal and the associated rocks, the immensely long periods of stable conditions indicated by the thickness of some coals, and some others which will suggest themselves to the reader. It is true that these are all purely local in character, but they occur at many though somewhat widely separated localities. The explanation for some of them must await the solution of certain problems in physical and chemical geology, lying wholly outside of the questions considered in this memoir.

These matters, however, do not concern the general problem with which this study has been concerned. In the present state of knowledge, as revealed in the literature, that finds its solution in autochthony alone.

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THE FLUTING AND PITTING OF GRANITES IN THE TROPICS.

(PLATES I–VIII.)

By J. C. BRANNER.

(*Read April 4, 1913.*)

Fluting is a peculiar minor form of topographic relief, but where it occurs over an area large enough to attract attention, it is a very striking feature.

All geologists are familiar with the fluting of limestones, which is a common phenomenon all the world over. Many fine examples of the fluting of limestones are given in Dr. H. Stille's "Geologische Charakterbilder," 10 Heft, published at Berlin in 1912, in which they are called "Karren."

But the fluting of granites or of other crystalline rocks is, so far as I have been able to learn, confined to tropical, and possibly subtropical countries. Two cases that occur on the coast of the state of Pernambuco in Brazil were mentioned by me in a paper on rock decomposition published in 1896.[1] Since that paper was published I have seen in Brazil some very striking examples, and have seen photographs of several others. Good examples are also cited by Max Bauer, who speaks of them as furrows (Rillen).[2]

[1] J. C. Branner, "Decomposition of Rocks in Brazil," *Bul. Geol. Soc. Amer.*, VII., 280, Rochester, 1896.

[2] *Neues Jahrbuch f. Mineralogie*, 1898, II., 192, and Plate XI.

The cases mentioned by Bauer occur in granites at Point Larue on the Island of Mahé, one of the Seychelle Islands in the Indian Ocean, about latitude 4° 30′ south, and longitude 55° east.

The most impressive examples of the fluting of crystalline rocks that I have ever seen were found in 1911 near the village of Quixadá in the interior of the state of Ceará, Brazil (Plate I.), latitude 5° 5′ south and longitude 19° 20′ west at an elevation of 180 meters above tide. In the vicinity of Quixadá almost every elevated exposure of the granites shows more or less fluting. Only those of which the best photographs were obtained are shown in the accompanying plates. The hills shown in these pictures are from 100 to 225 meters high, that is above their bases. Efforts to get photographs of the fluting about Quixadá have been only partially successful, as may be seen from the illustrations given with the present paper. Horace E. Williams of the Serviço Geologico do Brazil has sent me a photograph of fluted granites in the Serra de Borborema, 25 kilometers south of Campina Grande in the state of Parahyba.

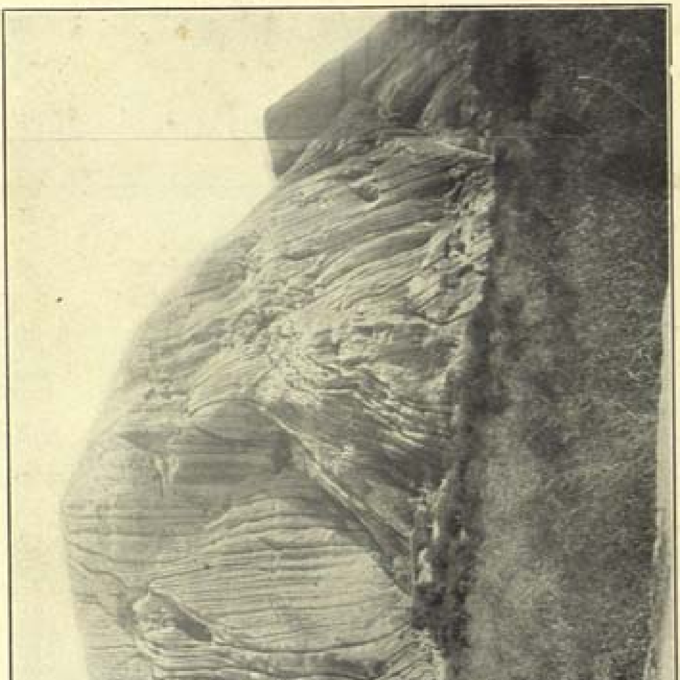
Other cases that have come to my attention occur in the interior of Ceará, and about the famous Itatiáya, the loftiest peak in Brazil, situated in the extreme northwest corner of the state of Rio de Janeiro. Itatiáya has an elevation of 2,994 meters above tide. The fluting of that peak was mentioned to me many years ago by Mr. Derby, the present director of the geological survey of Brazil,[2] but I did not then fully realize the extent and amount of it.

Recently I received from Dr. Carlos Moreira, of the National Museum at Rio de Janeiro, some photographs made by him of the Itatiáya peaks together with specimens of the rocks themselves. Dr. Moreira spent some forty-five days on and about that peak, and though his photographs are small, they are clear, and they are the best we have thus far seen of the fluting in that particular region (Plate II.).

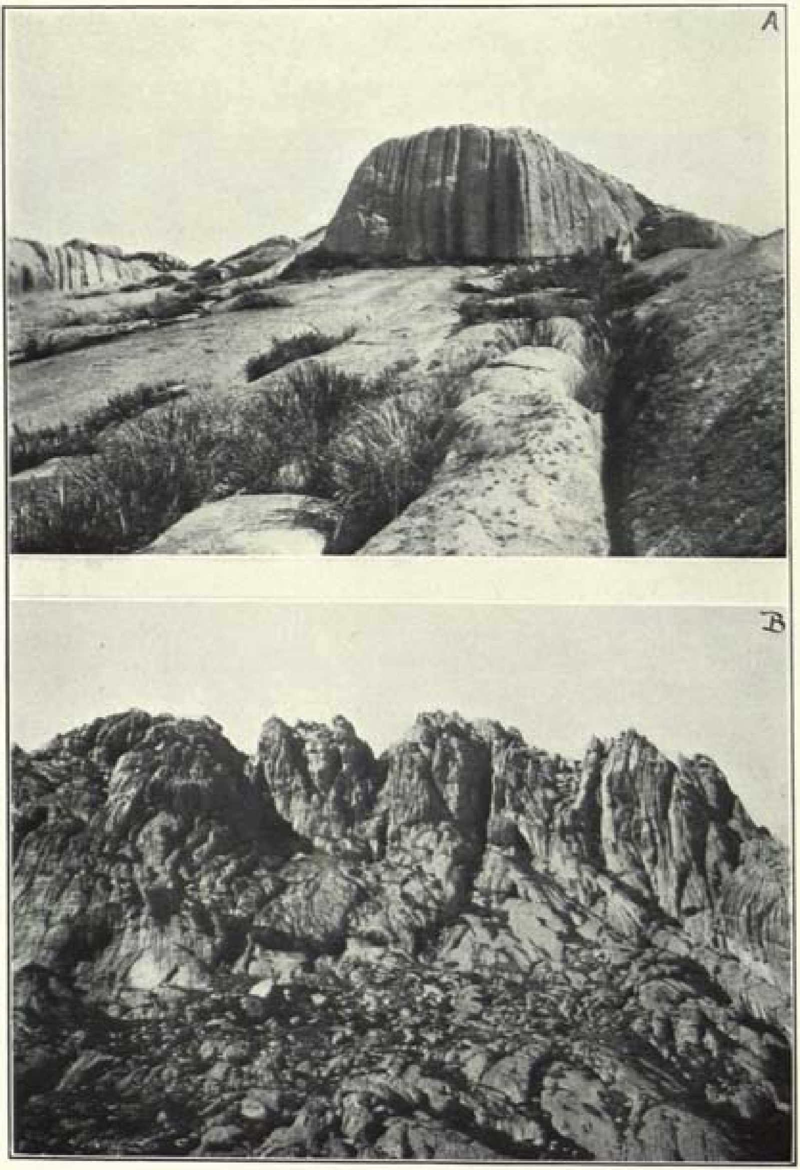
Characteristics of the Fluting of Granites.

In the fluting of limestones there is generally left at the crest of

[2] *Bul. Geol. Soc. Amer.*, VII., 280, footnote.



Serra Riscada near Quixadá, Estado do Ceará, Brazil. Height of the hill above its base, 226 meters. Inspectoria de Obras Contra as Seccas, phot., 1911.



Fluted syenite on and about the summit of Itatiáya, State of Rio de Janeiro, Brazil. Carlos Moreira, phot.

the miniature watersheds characteristic sharp, but somewhat ragged, combs of the rock. Between these divides are narrow, round-bottomed furrows or grooves that run down the slopes of the rocks by the shortest routes. These shallow grooves suggest the marks made by the fingers when drawn across a mass of plastic clay or putty. The furrows or grooves in limestone, however, are, as a rule, only an inch or so in diameter; that is the fluting of limestones is not usually on a large scale.

The illustrations given in Dr. Stille's "Geologische Charakterbilder," Heft 10, however, show flutings in limestones of various kinds, and some of these have unusually large furrows.

The fluting of granites and other coarsely crystalline rocks, however, is on a large scale, and the grooves have only a remote resemblance to those on limestone surfaces. The fluted surfaces necessarily appear only where the rock is entirely bare of soil. For the most part the furrows start at the summit of the exposed rock or as near it as possible, and run straight down the rock slopes by the shortest possible routes. Those seen at and about Quixadá reach a maximum depth of nearly two meters measured at right angles to the general surface of the rock masses. This takes no account of the ordinary gullies cut by the larger streams. Instead of having sharp combs separating the drainage areas of the different furrows, the divides or miniature watersheds on the granite surfaces are always rounded. But while the surfaces of the granite rocks are rounded in general outline, they are quite rough, this roughness being caused by the coarse crystals standing out boldly over the entire exposed rock surface. About Quixadá the rocks contain but little quartz, and feldspars are the minerals that produce this roughness of surface.

Caldron-like Pits.

In the Quixadá region the fluted rocks are covered here and there with great rounded caldron-like pits some of which are associated directly or indirectly with the fluting. These pits are shown in some of the accompanying illustrations (Plates III., IV., V.). They are not usually very deep, that is, they seldom exceed a depth of two meters

when isolated, and they reach a diameter of two meters or more, though they are generally not so wide. The fluting sometimes has the appearance of originating in these caldrons, but this seems to be due to the water overflowing and cutting notches in the rims on one side and thus merging the pits and the fluting into each other. In some cases I have seen a series of these pits in a nearly vertical row

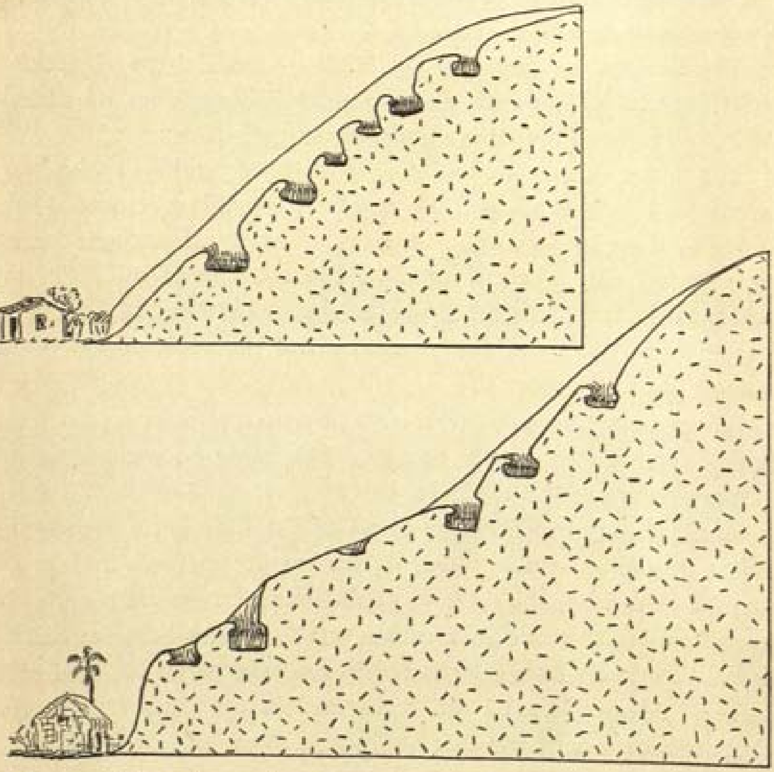
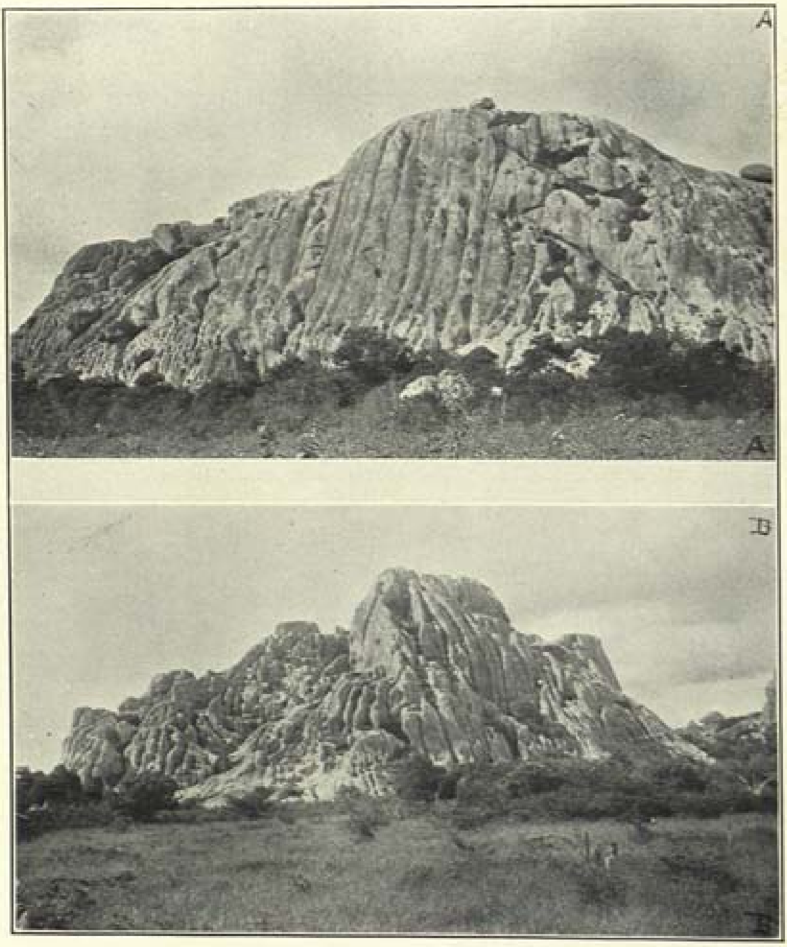


FIG. 1. Composite sections down the pitted and fluted rock surfaces at and about Quixadá showing the general forms of the caldrons.

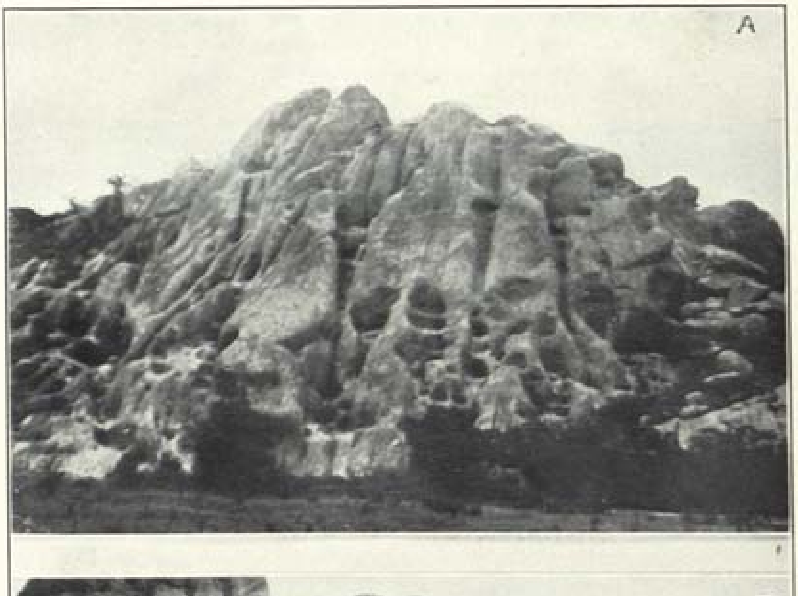
and connected by a furrow that gives the whole the appearance of a great irregular staircase mounting the hill (Fig. 1).

These caldrons are very abundant in some of the rocks, while in others they do not appear at all. They occur on the tops of mountains, hills, or bosses, on the sides and at the bases; they are mostly



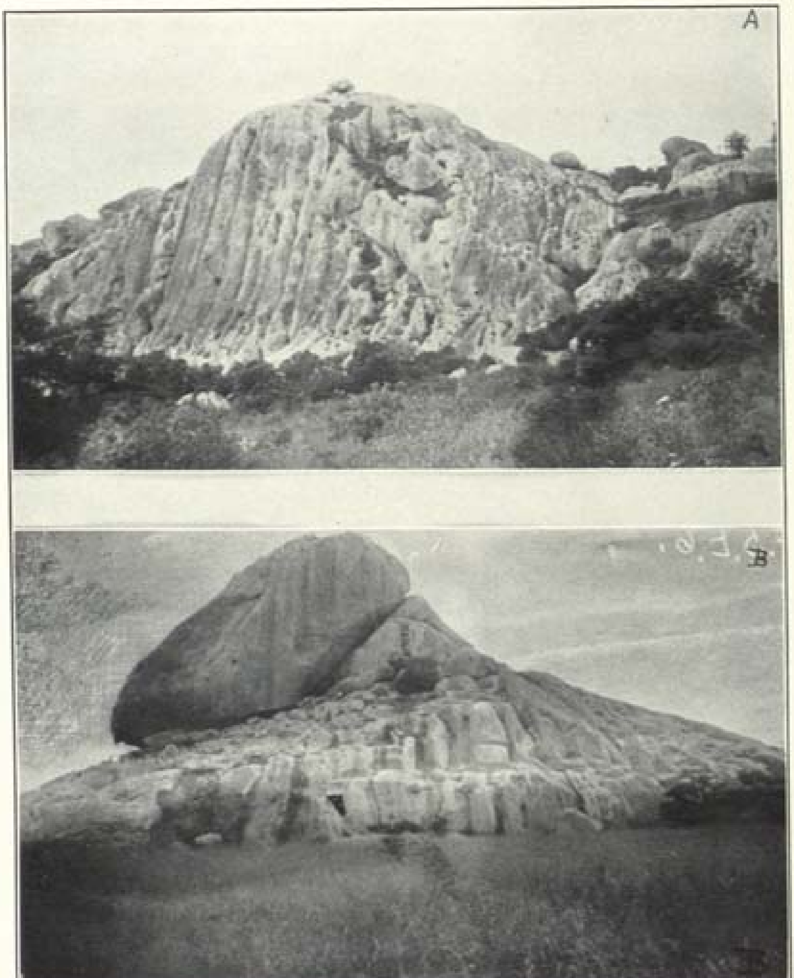
A. Fluted and pitted hills at kilometer 183, near Quixadá, Ceará. Waring, phot., 1912.

B. Fluted and pitted hills at kilometer 183½, near Quixadá, Ceará. Waring, phot., 1912.



A. Pitted syenite east of the railway near Quixadá, Ceará. Waring, phot., 1912.

B. Pitted granodiorite near Quixadá. E. Leib, phot., 1911.



A. Fluted and pitted granodiorite near Quixadá, Ceará. E. Leib, phot., 1911.

B. Pitted granite between the stations of Junco and Quixadá. E. Leib, phot., 1911.

vertical or nearly so, but some of them are also nearly horizontal. At Quixadá they are more abundant on the gentler slopes and especially about the bases of the hills. In Plate V., Fig. *B*, for example, there is a striking difference between the fluted surface in the upper part of the hill and the pitted and fluted surface of the rock about the base of it.

The great rock in the edge of the village of Quixadá is a striking illustration of the combination of pits and of fluting, though the caldrons are the more marked feature of this particular mass (Plate VI., Fig. *B*). The photographs of Itatiáya show the surface to be pitted here and there, but the pits appear to be formed on vertical walls as well as on sloping or flat surfaces (Plate VII., Figs. *B*, *C*).

A good deal has been made of pits or pot-holes in the granites in other parts of Brazil. In Hartt's "Geology and Physical Geography of Brazil," at pages 314–315, is an account of holes observed in granites in the interior of the state of Bahia. Following are the notes of J. A. Allen on the region southeast of the Serra de Jacobina.

"At frequent intervals there were singular holes in the rocks, usually nearly filled with water, to which the inhabitants give the name 'caldeirões.' These 'caldeirões' are of frequent occurrence, but I was unable to learn whether all were of a similar character. Nearly all of the considerable number examined proved to be genuine pot-holes, and some of them were of great size. The largest one I measured was elliptical in outline, eighteen feet long, nine or ten in width, and twenty-seven deep, with smoothly worn sides. Beneath the water that partially filled it there must have been many feet of materials that for ages have been falling into it, so that its whole depth must be much greater than my measurements indicate."

Professor Hartt adds the following as a footnote:

"Mr. Allen tells me that these pot-holes often occur out on the plain, far away from any high land, and that they are sometimes found excavated in the summits of slight bulgings in the plain, or even on the top of a hill, as in the case of the Morro do Caldeirão. These holes must have been excavated by falling water. There is only one suggestion that I can make as to their origin, and that is that they were formed by glacial waterfalls, in the same way as the pot-holes found over the glaciated regions of North America, as, for instance, in New Brunswick and Nova Scotia, where I have had an opportunity of examining them. It is well known that glacial waterfalls, notwithstanding the constant movement of the ice, are very often stationary, and

in the Alps they hollow out enormous pot-holes in the rocks. The lake plain is noted for the small amount of decomposition which has taken place over it, owing, I believe, largely to the fact that it has never been covered by the virgin forest, having always been dry."

The explanation here suggested will be referred to later.

Character of the Fluted and Pitted Rocks.

The fluting of crystalline rocks is not confined to any one particular kind of rock, as was at first supposed, except that they are all massive and homogeneous. Those about Quixadá in Ceará vary somewhat, but they are mostly massive coarse grained, gneissoid granodiorites, and the weathered surfaces, though rounded in outline, are very rough, owing to the feldspar crystals standing out over them in high relief.

The rocks are often more or less jointed, and the joints necessarily interfere with the regularity and extent of the fluting, though they do not prevent it. Possibly abundant jointing may so interfere with fluting as to render it quite inconspicuous.

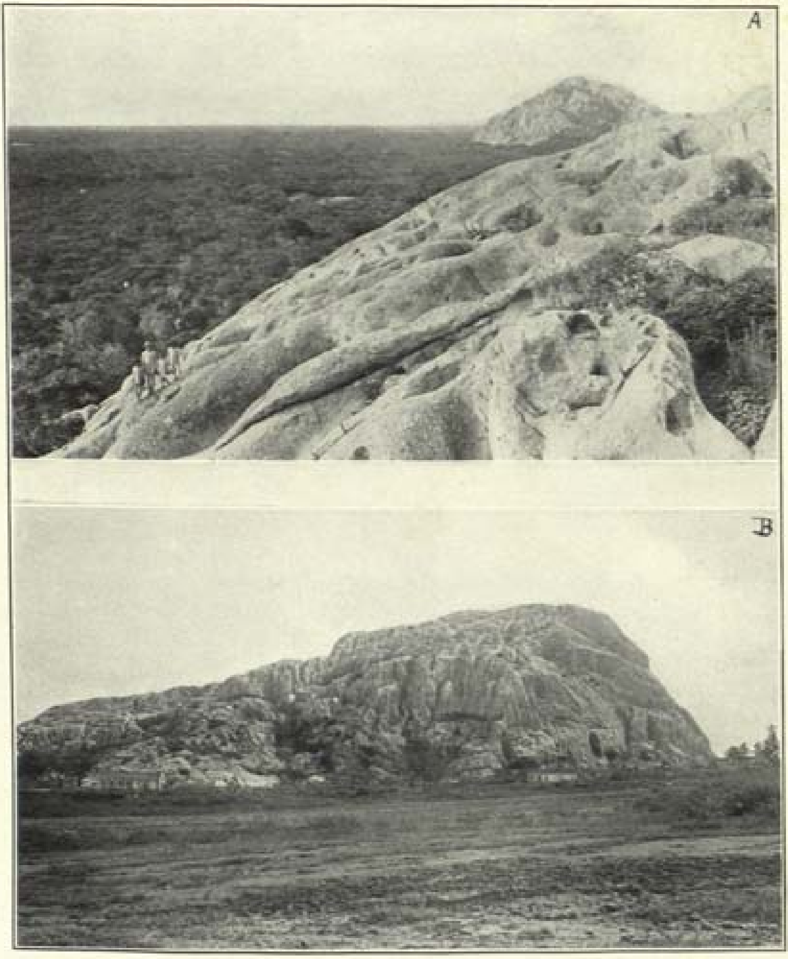
The fluted rocks of the Itatiáya group are massive homogeneous, coarse grained syenites, somewhat jointed, the joint planes having various angles with the horizons, as may be seen in the accompanying illustrations. The Itatiáya syenite is not as coarse grained, however, as the granodiorite of Quixadá.

The fluting mentioned by Bauer in the Seychelle Islands is said to be in granite. The examples seen by the writer in the state of Pernambuco are all in granites.

Origin of the Fluting.

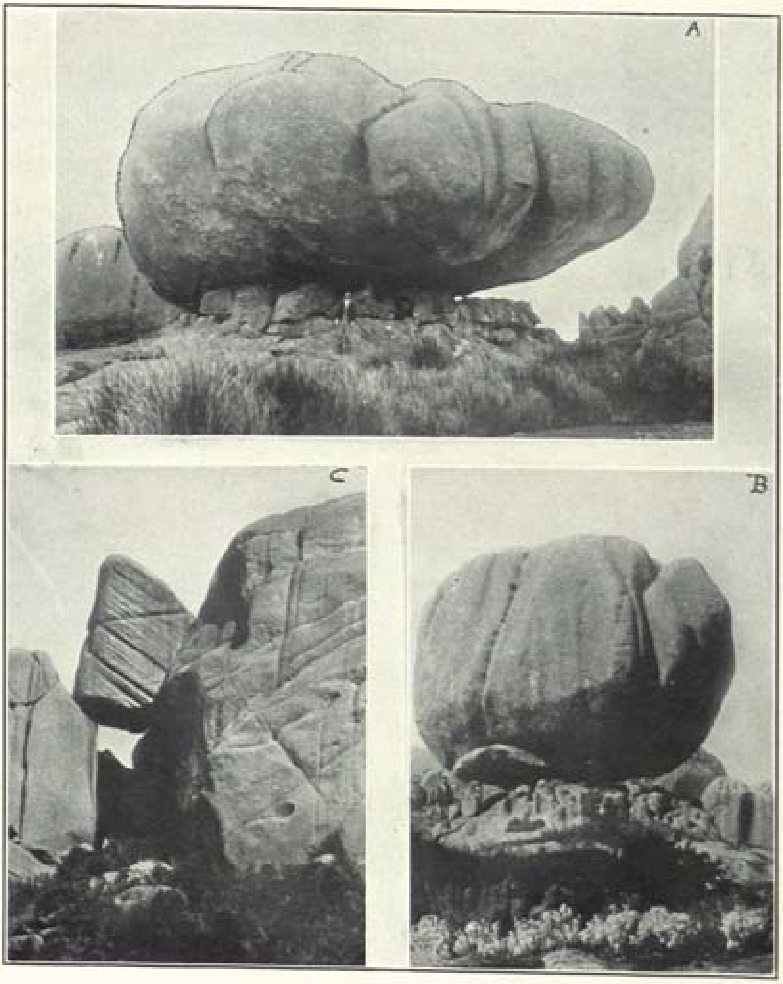
It was supposed at the outset that chemical action over openly exposed surfaces would turn out to be an important factor in the production of the fluted forms. But it does not appear that such action is especially important. It is evident that the rocks are chemically affected by the alteration of the feldspars, but there is no apparent localization of that action in the case of the fluting.

It seems most probable that in the long exposure of these homo-

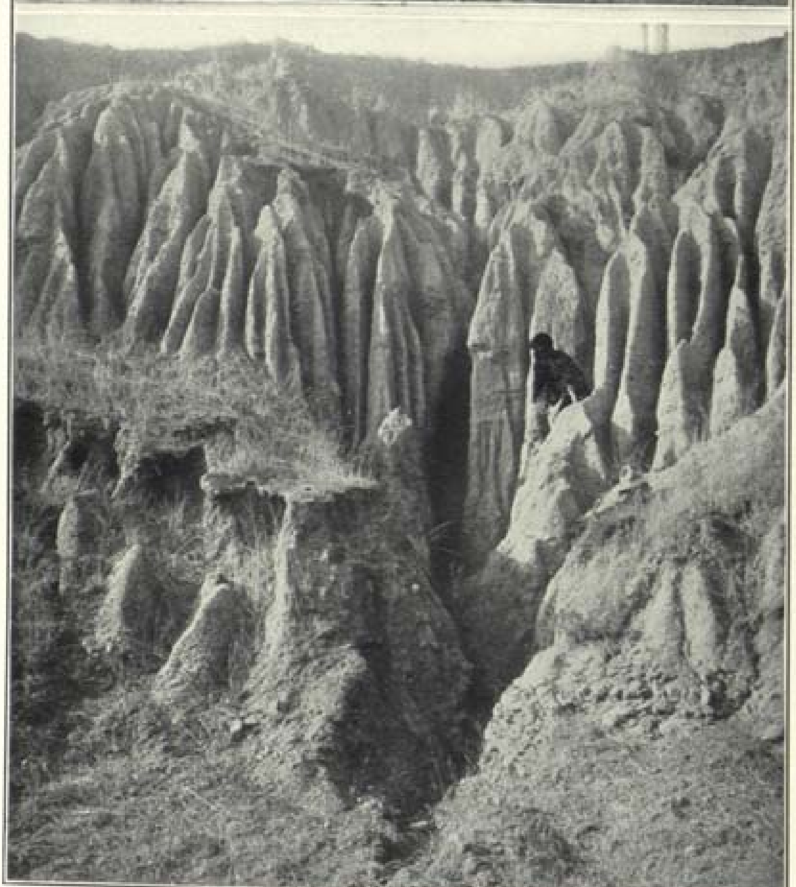


A. Top of fluted hill at kilometer 182½, near Quixadá, Ceará. Waring, phot., 1912.

B. The fluted and pitted granodiorite hill at Quixadá, Ceará. Altitude about 200 ms. Waring, phot., 1912.



Fluted boulders of decomposition in the vicinity of the peak of Itatiáya. Fig. C shows a fluted mass that has been overthrown so that the fluting is no longer vertical. Carlos Moreira, phot.



Fluted banks of sandy clay, San Bruno Mountains, south of San Francisco, Cal. Branner, 1912.

geneous rocks, the water running down the slopes sweeps along mechanically the loosened fragments of the minerals just as it would remove anything else. Channels are necessarily deepened most rapidly where most water flows, and in the process of rock removal, as a whole, the bottoms of these channels always keep in advance of the divides between them. That is, it is a narrow localization of mechanical action by water.

It is especially noticeable that the fluting is a slow process, and this slowness is explained by the fact that each furrow is made by the little water that falls within its own narrow drainage basin.

One may occasionally see in soft sandy clays furrows very similar in form to the fluting of granites. There are some rather striking examples in the San Bruno mountains just south of the city of San Francisco in California. One of the accompanying plates (Plate VIII.) shows two photographs of these particular gullies. These photographs of gullies were made in January, 1912.

The materials of these furrowed banks are sandy clays containing angular and subangular pebbles and rock fragments—apparently soil and other products of the breaking down of the shales and sandstones of the San Bruno mountains. These materials also remind one of the stone-capped earth-columns of the Tyrol, though in the present case the stone caps are wanting.

Such earth-columns are supposed to be the work of the mechanical impact of rainwater. But most of the San Bruno furrows have the appearance of being made, not necessarily by the impact of raindrops, but by the running down of the water that falls on and over the furrowed surface.

Water flowing down from the slopes above cuts the deeper gullies in the face of the bank, but the minor trenches are supplied only by water that falls on the immediate surface.

The even spacing of these furrows is one of their striking features. This is due I presume to the fact that, owing to the rather even surface and the evenness of the water supply, there is usually nothing to enable a channel to gain on its neighbors.

THE ORIGIN OF THE CALDRONS.

The suggestion of Hartt quoted on a preceding page in regard to the glacial origin of caldrons or pot-holes in the interior of Bahia must be set aside as quite out of the question, either for the ones in Ceará or for those in Bahia.[4] There is absolutely no evidence of Pleistocene glaciation in Brazil.[5] The pot-holes mentioned by Hartt and Allen in the interior of Bahia, in every case with which I am acquainted, have been cleaned out by man for the purpose of using them for water storage in times of drouth. They have but little in common with the caldrons referred to in this paper.

The Quixadá pits are in process of development, and they are evidently therefore to be explained by agencies now in operation. Aside from the openly exposed bare surface of a coarsely crystalline homogeneous rock, the factors that enter into the problem appear to be: The slope of the surface, the localization of incipient depressions, disintegration and chemical alteration of the rock forming minerals by the action of rainwater aided by organic and other acids, the concentration of rainfall, and the mechanical floating away of the disintegrated and finely divided minerals.

It seems probable that the original location of the incipient caldrons is purely accidental. Once begun, however, the standing water attacks the constituent minerals of the rock in the bottom of the pit. It is quite noticeable that in the great majority of the caldrons, perhaps in all of them, the walls are somewhat overhanging. This overhanging is due to the fact that once a pit is started, the water standing in it tends to moisten and affect a widening surface.

As soon as a depression is deep enough to retain some of the rainwater, plants begin to grow in it, and insects are drowned in it, and as these things decompose the organic acids thus produced enable the water to attack the minerals more readily.

The concentration of the rainfall of the region causes the pits to be filled with water for only a part of the time. The rest of the time the pits are dry or they are only moist on the bottom.

It has been suggested that deflation may be an agency in the for-

[4] Hartt's "Geology and Physical Geography of Brazil," pp. 314–315.
[5] "The Supposed Glaciation of Brazil," *Jour. Geol.*, I., 753–772.

mation of these caldrons. In my opinion deflation may be important in the early stages of excavation, when the depth does not prevent the wind from blowing away small loose fragments of the minerals, but when a pit is a meter or more in depth and a meter in width it seems highly improbable that the wind is a factor of any importance in the direct removal of materials, though it may be indirectly important enough in the bringing of plant seeds or spores.

The things that seem to me competent to account for the removal of the disintegrated minerals are suggested by the dark lines that run down the rocks from the notches in the lips of all of the caldrons. These dark streaks are made by overflowing water.

When water stands for some time in the pits it becomes covered by low forms of plant life, apparently freshwater algæ for the most part. When in time the water dries up this material is left spread over the bottom where it packs together, a sticky fibrous mass clinging to and closely enwrapping whatever lies in the bottom of the pit. In time the rains come again and the pit is filled to overflowing, the matted masses of algæ are floated to the top and carried over the edge of the caldron, taking with them some of the mineral fragments from the bottom of the pit. The rapid growth of vegetation in such waters is greatly facilitated by the hot climate, while the hot dry air and the high winds quickly dry up the waters when once the pits are filled by the rains. The peculiar concentration of the rainfall at Quixadá likewise hastens this natural process of excavation.

Still more important in most instances is the stirring of the materials in the bottoms of the caldrons by the inflowing water. The mud in the bottom being thus stirred by the water pouring in, a great deal of the finer material is carried out when the pit is full and overflows its lower lip. It must not be supposed, however, that the water flowing into the caldrons is of sufficient volume to whirl the coarse materials and thus grind out the rock. This is far from being the case. I found no evidence of any such mechanical wear on the insides of the pits. They are all uniformly rough within.

When the pits are shallow, however, and are so far down the slopes that the water enters them with a rush it is readily imagined that all or most of the finer materials must be swept over the rim. Some of the forms suggest that old and deep caldrons have from

time to time been obliterated by the breaking down of their lower lips.

Fortunately we have the records of the rainfall taken at Quixadá from 1891 to 1906.[6] These records show that during those fifteen years the total precipitation was 10,711 millimeters. Distributed by months, the greatest rainfall was in February, March, April, and May when it reached an average of 134 millimeters a month; the minimum fell in August, September, October, and November with an average of 17 millimeters per month.

These figures taken alone, however, do not give a clear idea of the climatic conditions in the semi-arid region about Quixadá. An important fact that bears directly upon the question of the origin of these caldrons is that the rains are frequently torrential while they last, even during the dry season, and that they are often followed by periods of drouth during which the hot dry atmosphere quickly takes up the water filling the caldrons. For example, the table of rainfall shows that in October, 1894, there was a precipitation at Quixadá of 96 millimeters in a single day, and that too in the dry season. In December of the same year 95 millimeters fell in two days; in July, 1904, the rainfall was 147 millimeters in two days. In the last case this heavy rain was followed by nearly five months of complete drouth. But even in the absence of long drouths, the rapid evaporation and high winds and high temperatures would empty one of these caldrons in a short time. The temperature at Quixadá[7] in 1897 ranged from an absolute maximum of 36.2° C. to an absolute minimum of 22.1° C.

Statistics dating back to 1711 bear out the generally accepted fact that the interior of Ceará is a region of frequent drouths. In the 189 years from 1711 down to and including the year 1900 it is claimed that there have been thirty-one years of drouth.[8] But even the years of drouth may have had rain enough to overflow the cal-

[6] Thomaz Pompeo de Souza Brasil, "O Ceará no começo do Seculo XX.," Fortaleza, 1909, p. 330.

[7] F. M. Draenert, "Zum Klima des Staates Ceará, Brasilien," *Meteorologische Zeitschrift*, April, 1903.

[8] Raymundo Pereira da Silva, "O Problema do Norte." Rio de Janeiro, 1907, p. 7.

drons several times without there being enough to answer the purposes of the planters and cattle growers.

It may be worth noting also that in dry seasons, and as long as the water lasts, birds and other animals flock to these caldrons to drink.

The total result of the alternation of rain and drouth must be a frequent filling and emptying of the pits, a frequent stirring up of the fine materials in the bottoms of the pits, and its removal in mechanical suspension by the water overflowing the lips of the caldrons.

These facts also suggest why the caldrons are most abundant about the lower slopes rather than on the crests of the hills: there is a larger run-off, and consequently a more frequent and a more vigorous disturbance of the water in the pits.

The horizontal pits occasionally seen in vertical rock walls are evidently not made in the same way as the vertical pits formed in flat or sloping surfaces. The latter seem to be due to the alternate absorption and evaporation of water much as fret-work is formed over the surfaces of porous sandstones by the prying off of sandgrains. Some remarkable cases of this kind are known in the interior of the state of Bahia in Brazil. Instances of this sort are now being studied and no further mention of them need be made at present.

Conclusions

The fluting and pitting of coarse grained crystalline rocks appears to be confined to tropical countries, and to massive, homogeneous rocks openly exposed.

The grooves that make up the fluted surfaces run down the rock faces by the shortest possible courses, and are made by the small amount of water that falls upon and flows down the fluted surfaces themselves. In other words there are no strong streams flowing across fluted surfaces whose waters are gathered over a wide area.

Fluting seems to be confined to steep slopes. The angle of such slopes cannot be stated, but in the cases observed it usually was forty-five degrees or more.

The process of fluting is partly chemical and partly mechanical

and physical. As a whole the process is necessarily a slow one. The localization of the run-off leads to an approximately even spacing of the small streams and consequently to the even spacing of the fluting where it appears over a broad surface. Somewhat similar erosion forms are to be seen occasionally in homogeneous sandy clays, though owing to the character of the materials the latter are cut rapidly.

Though fluting seems to be confined to tropical countries, it is worth noting that the temperature on the Serra do Itatiáya in Brazil, where fluting is very marked, often falls below freezing. Evidently some freezing does not interfere with fluting.

Caldron-like pits are associated with fluting, and occur chiefly on slopes not so steep as the fluted ones. They are most abundant on the lower parts of the bare rock surfaces. They are formed by water dissolving and disintegrating the minerals, and by the inflowing waters mechanically stirring and floating the finer particles over the rims of the basins. The chemical action of the water in the pits is hastened by the decay of plants and other organisms that live and die in the water left standing in the pits by the rain.

Exfoliation is not a prominent feature of the fluted and pitted masses. Indeed exfoliation hardly occurs at all in such places. Disintegration goes on rapidly, but it attacks the entire surface pretty evenly. The feldspars seem to resist weathering better than the accompanying minerals, at least the feldspars are left standing out in high relief over these surfaces. In time the mere heating and cooling of the feldspars breaks them up, and they are washed off by the torrential tropical rains as angular fragments or they are blown off by the winds.

The absence of talus about the bases of these fluted and pitted hills is very striking. Indeed there are quite as many boulders on the summits and sides of the hills as there are about their bases. This seems to be due to the even attack of disintegration over all surfaces, and to the fact that there is no freezing and thawing to chip off the upper surfaces of hills and rocks and to pile up the fragments at the bases of the slopes.

STANFORD UNIVERSITY, CAL.

ON THE PROSPECT OF OBTAINING RADIAL VELOCITIES BY MEANS OF THE OBJECTIVE PRISM.

By FRANK SCHLESINGER, M.A., Ph.D.

(*Read April 20, 1912.*)

Among the many problems that confront the workers in stellar spectroscopy at the present time, three stand out by reason of their importance. First, the classification of stars by means of their spectra. Second, the determination of absolute radial velocities for the purpose of determining the sun's way, and the relation between stellar spectra and stellar motions; and of throwing light upon various hypotheses regarding star-streaming. Third, the determination of the orbits of spectroscopic binaries.

In the second and the third of these problems the need of extending our determinations of radial velocities to faint stars has become very pressing. At the present day a comparatively large number of observatories are equipped with apparatus that, without involving unduly long exposures, will yield radial velocities for stars down to the fifth magnitude; but what is greatly desired is an extension to stars at least as faint as the eighth magnitude. It is futile to hope to attain such an extension by erecting more powerful telescopes and by attaching to them slit spectrographs of even the most approved design. Experience has amply shown that in work of this kind the gain that comes with increasing the size of the telescope is only very slight. The principal reason for this is the loss of light at the slit, which under favorable circumstances in the case of telescopes of the largest size must frequently be as much as ninety per cent.; and under certain atmospheric and instrumental conditions this percentage of loss may be considerably increased. With smaller telescopes the loss of light at the slit is not so serious, and for this reason, as well as for others, it is a fact (to cite somewhat extreme cases) that the spectrographs attached to certain telescopes having

apertures from twelve to fifteen inches have proven nearly as efficient for the determination of radial velocities as those attached to telescopes of two or three times their aperture.

If, therefore, we are to seek any considerable extension of these observations to fainter stars, we are forced to turn to the objective prism, the great advantage of this form of spectroscope being its economy of light. Few slit spectrographs now in use utilize more than one per cent. of the light that falls upon the objective of the telescope to which they are attached. With the objective prism, as much as twenty-five per cent. may easily be realized with a proper choice of materials in the objective and in the prism, and providing also that the thickness of the prism is not too great. Furthermore, with the slit spectrograph we secure the spectrum of only one star at a time, whereas with the objective prism all the stars in a considerable area of the sky impress their spectra upon the same plate. On the other hand, the difficulty of securing points of reference from which the shifts in the lines may be measured has thus far proved an insurmountable obstacle in the way of obtaining even fairly accurate velocities by this means.

Spectra produced by diffraction gratings are nearly normal; that is, the distance between any two lines is approximately proportionate to their difference in wave-length. In such spectra the shift due to velocity is greater for lines of greater wave-length. Consequently, the spectrum is lengthened if the star is receding from us and is shortened if the star is approaching. On the other hand, spectra produced by prisms are far from being normal, lines in the region of greater wave-length being crowded together, while those at the violet end are more widely separated. In this case, shifts due to velocity become reversed in their relative amounts, being now greater for lines of shorter wave-lengths. Prismatic spectra are accordingly shortened for receding stars and lengthened for those that are approaching us. We see, then, that the lengths of both prismatic and diffraction spectra are changed by radial velocity, and accordingly the latter can, theoretically at least, be found by measuring the distance between two lines widely separated in the spectrum.

The possibility of determining velocities in this way seems first

to have occurred to Pickering, who suggests and dismisses it in a single sentence, on page xxi, Volume 26, *Annals of the Harvard College Observatory*. A few years later the same method was independently proposed in a somewhat different form by Orbinsky[1] and also by Frost.[2] None of these suggestions seems to have been taken up by astronomers, and so far as I know there is no record of any actual experiment dealing with the length of spectrum from the point of view of radial velocity.

Whatever may have been the promise held out by these proposals when they appeared twenty years ago, I should like to point out that their chance for leading to valuable results may be greatly increased by the use of modern photographic plates. Recently several investigators have shown us how to prepare plates that are sensitive throughout a far greater range in wave-lengths than was hitherto the case. Formerly, only the region to the violet side of the F line (λ 4,860) could be photographed without necessitating very long exposures; but now we have at our disposal comparatively rapid plates that will yield spectrograms of nearly uniform density from the K line at λ 3,933 to the D lines at λ 5,895, or even to the C line at λ 6,563. With former spectra the shift in the lines in the violet region could be ascertained by referring them at best only to lines in the neighborhood of λ 4,800, which themselves share the same shift to a considerable extent. But the yellow and red portions are so closely crowded in prismatic spectra, that lines in this region would show very little shift due to velocity, and hence would form excellent points of reference for lines in the blue and violet.

To carry out this plan, an ordinary objective, whether corrected for photographic or for visual rays, would not answer, since it is necessary to have in focus at the same time lines in both regions. Cooke in England has successfully put upon the market an objective,[3] made up of three different kinds of glass, which brings into good focus the entire range of spectrum from λ 3,800 to λ 6,000. An objective of adequate aperture of this type would serve the present

[1] *Astronomische Nachrichten*, **138**, 9, 1895.
[2] *Astrophysical Journal*, **2**, 235, 1895.
[3] Designed by Mr. Dennis Taylor.

purpose fairly well. It would be still better to design an objective with this specific application in view and to bring into focus the two regions say from λ 3,900 to λ 4,500 and from λ 5,900 to λ 6,600, without paying much attention to the intermediate region, from λ 4,500 to λ 5,900.

It would be quite possible to use a reflecting telescope for this purpose. But as compared with a refracting telescope the reflector seems to be less promising for two reasons: first, because of the change in the focal length with change of temperature; and, second, because of the harmful effect of any change in the inclination of the mirror. Thus, if one edge of a mirror whose aperture is one tenth its focal length should be tilted with respect to the other edge by only one micron, the lines in the spectrum would be shifted by twenty times this amount, a quantity that is of the same order as the shift due to velocity. In refracting telescopes the effect of a slight tilt in the objective is of no consequence whatever.

With the objective prism it is difficult to make long exposures that will show sharp spectra. This is chiefly because the refractive index of glass varies rapidly with the temperature and the amount by which the rays of light are deviated is thus continually changing if the prism is in the open air. Observers with slit spectrographs have long been aware of the necessity of guarding their prisms against changes of temperature, and have learned to surround them with cases within which the temperature is artificially kept from fluctuating. As I pointed out a few years ago,[4] there is no reason why a similar device should not be used in connection with objective prisms. In this case, the light from the star should first be admitted through a window of optically plane parallel glass, whose aperture is the same as that of the prism and the objective. This window should form part of a temperature case enclosing the whole camera, including the prism, the objective and the plate-holder. The case can then be maintained at constant temperature in the usual way.

Even with these precautions it would be well, in the experimental stages at least, to calibrate the prism frequently by means of stars whose velocities are known from observations with slit spectro-

[4] *Science*, 30, 729, 1909.

graphs. More than a thousand such stars are available at the present time and in a few years this number will be at least doubled; so that there should never be any great difficulty in finding a suitable test object close at hand. The process of observing would then perhaps consist of an exposure on a star whose velocity we wish to determine, immediately followed in each case by an exposure (made on the same plate close to the first) on a neighboring star whose velocity is already known. The difference of the lengths of these two spectra is then to be measured, converted into units of kilometers per second and applied to the known velocity.

A quarter of a century ago the suggestion was made by Pickering, in connection with his experimental work for the Draper Memorial, that radial velocities could be determined from objective prism spectra if some absorptive medium could be found that would produce one or more narrow and sharp absorption bands. If such a substance were interposed at any point in the spectrograph, or indeed anywhere between the star and the plate, the resulting spectra would also show these bands in positions not affected by the velocity of the star, and would thus offer a beautifully simple method for determining velocities. Pickering made a search for a substance with this very desirable quality, but at that time did not succeed in finding a satisfactory one. Recently, however, he suggested this subject to Professor R. W. Wood, who after experimenting with various compounds has proposed neodymium chloride for this purpose. This substance introduces into the photographic region of the spectrum a number of absorption bands. One of these, at λ 4,272, is sharp and fairly narrow, having a width of about three angstroms, a quantity that corresponds to a velocity of about 200 kilometers a second. This substance seems, therefore, to offer a method for measuring the velocities of certain stars with a moderate degree of precision. Just how accurately this can be done, we must wait for actual experiments to tell us; and such experiments are under way in at least two observatories. There can be little doubt that an accuracy represented by a probable error of not more than ten kilometers can be attained in this way. This Pickering-Wood method is hardly applicable to any but stars of the A and B types. In stars

of the F type and beyond, the neodymium line or band at λ 4,272 becomes involved with lines that are proper to the star itself, and accurate settings upon it become impossible.

A number of other suggestions have been made for utilizing the objective prism for determining velocities, but I shall stop to consider only one of these. Like the two proposals that we have already described, this method owes its origin to Pickering,[5] who seems to have studied this problem to good purpose long in advance of any other astronomer. Let us suppose that we have secured by means of the objective prism a photograph showing the spectra of a number of stars in the same region, and that the prism has been so oriented that the violet end of each spectrum is toward the north. Suppose further that we have measured accurately the position of the K line in each spectrum. From these measurements we might compute the relative declinations of the stars, but these declinations would be in error by a slight amount on account of the unknown radial velocities of the stars. Thus a star that is approaching us would have its K line shifted toward the violet end, or in this case, toward the north, and the computed declination would be too great. Let us then secure another photograph of the same region with the prism reversed, so that now the violet end of each spectrum is toward the south. The approach of a star would as before shift its lines toward the violet, which is, however, now toward the south. We should therefore derive a relative declination for the star that is as much too small as it was too great in the first instance. It is obvious, then, that the measurement of such a pair of plates would theoretically give us the data from which the relative velocities of all the stars on the plate might be inferred. Pickering further proposed that the prism be reversed by simply reversing the telescope on its equatorial mounting, and that the comparison of the two plates could be facilitated by taking one of them with the glass side outward. The plates could then be put film to film and the measurements would become differential.

Although the theory of this method is simple enough, its practical

[5] Harvard College Observatory Circulars, No. 13; see also *Astronomische Nachrichten*, 171, 137, 1906.

application is a matter involving serious difficulties. A number of modifications have been proposed with a view to obviating one or another of these difficulties. Thus Stewart[6] suggested that, instead of making exposures upon two different plates, two objectives and two oppositely placed prisms be employed for making two simultaneous exposures side by side upon the same plate. The plate would then have to be inclined equally to the two incident beams, and, under ordinary circumstances, it would be possible to secure only one pair of spectra upon each plate. Another modification is that due to Comstock,[7] who proposed that the two halves of the objective be covered by two prisms having their refracting edges turned toward each other. These prisms are to be compound and of the "direct-vision" variety, so as to yield for each star a pair of spectra in close juxtaposition. Here, however, we encounter the difficulty of securing prisms of sufficient size, for prisms of this description would have to be very thick in order to give spectra of sufficient dispersion. The present writer has suggested still another modification,[8] in which the two plates are taken simultaneously by means of two independent (but similar) cameras and prisms, both being enclosed in a constant temperature case provided with two suitable windows of plane parallel glass.

The advantages of securing the two photographs at the same time are two-fold; first, this obviates any necessity for considering refraction, a very bothersome matter when large fields are in question. Second, the so-called guiding error is eliminated. Whether the telescope is driven entirely by clockwork, or whether the observer attempts to secure more perfect guiding by introducing slight corrections by hand, the spectra will still wander a little from their mean positions and the place at which an observer will bisect a line in the spectrum will depend somewhat upon the nature of the guiding. If, however, the direct and the reversed spectra are secured simultaneously, the guiding error will be the same for both and will have no effect upon the derived velocity.

In this method of determining velocities there remains a difficulty

[6] *Astrophysical Journal*, 23, 396, 1906.
[7] *Astrophysical Journal*, 23, 148, 1906.
[8] *Science*, 30, 729, 1909.

more serious than any that we have mentioned. This is the distortion of the field due to the presence of the prism. Let us suppose that there were in the sky a row of stars in the same right ascension and equally spaced in declination. Let us photograph the spectra of these stars with the help of an objective prism whose refracting edge is parallel to the equator. Then, quite apart from the effect of radial velocity, the spectra would by no means be equally spaced upon the plate, the intervals on one side of the center being all too small, and those on the other side all too great. When the prism is reversed, those spaces that were too large are now too small and *vice versa;* so that the distance between the two spectra of the same star depends upon its declination. I have computed this double distortion for a spectrograph whose dimensions are such as one would choose for this work, and have found it to amount to two millimeters at a point only two degrees of arc from the center. This quantity is about one thousand times as great as the accuracy that an observer would hope to attain in his measurements, so that it is readily seen how intimately he would have to become acquainted with his prism in order that he might apply this very large correction within the limit of accuracy that the case demands. Furthermore, there is an additional distortion of nearly the same size in the other direction. That is, if we could photograph a row of stars on the equator, their spectra on the plate would not appear in a straight line, but would lie in a curve that is approximately a parabola with its convex side toward the refracting edge of the prism.[9] If, therefore, the prism is reversed the curvature of this line is also reversed, and when the two plates are compared we again have a double distortion, depending now (in the position of the prism that we have imagined) upon the star's right ascension. It is worthy of remark that these distortions are smaller in the design proposed by Comstock than in any of the others. Furthermore, if we confine our attention to a single pair of spectra in the axis, as in Stewart's suggestion, these distortions do not enter at all.

We see, then, that the obstacles in the way of the practical appli-

[9] It is this same distortion that causes the curvature of the lines upon a slit spectrogram, the formula for which is given by Ditscheiner in the *Sitzungsberichte der Math. Klasse der k. Akademie zu Wein,* 51, part 2, 1865.

cation of this method are undoubtedly serious; nevertheless, they do not appear to be of the character that patience and perseverance on the part of a skillful observer will not overcome.

If the objective prism is ultimately to be used for determining velocities, it would be a great advantage to be able to utilize the full apertures of modern telescopes without necessitating objective prisms of corresponding size. In the case of reflecting telescopes, this might be done by replacing the flat secondary (of the Newtonian form) or the hyperboloid (of the Cassegrainian form) by a convex paraboloid, with its axis and focus coincident with the axis and focus of the primary mirror. The beam of light reflected from such a secondary would be a parallel one, contracted to perhaps one fourth or one fifth the diameter of the original beam. This reduced beam could then be made to pass through an objective prism of moderate size. Similarly, in the case of refracting telescopes, a diverging lens might be placed in the position that the correcting lens usually occupies when the telescope is to be used with a slit spectrograph.[10] This diverging lens can be so designed as to make the emerging beam of light parallel in any portion of the spectrum desired. For practical reasons it would not be advisable to contract the original beam too much; or in other words, to put the converging lens too near the focus of the visual or the photographic objective. In the case of reflectors, too, though for not quite the same reason, the paraboloid should not have too small an aperture and should not be placed too near the primary focus.

In conclusion, it seems to me that the prospect of obtaining radial velocities by means of the objective prism is good enough to warrant a trial of all three of the methods that have been reviewed above. If I were asked which of the methods seemed to me the most promising, I should say that the one which makes use of neodymium chloride would probably lead to immediate results, if we are to remain satisfied with a moderate degree of precision; but that the method which is concerned with the length of the spectrum might ultimately be developed to give considerably more accurate results.

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[10] Compare with the paper by Wadsworth, *Astrophysical Journal*, 16, 12, 1902.

THE HISTORICAL VALUE OF THE PATRIARCHAL NARRATIVES.

By GEORGE A. BARTON.

(*Read April 17, 1913.*)

Since the birth of the sciences in the nineteenth century, knowledge has been revolutionized and enlarged in every department. The effect of the creation of the historical and social sciences is as marked in this respect as that of the natural sciences. The account which the records and traditions of a country give of its history is found to begin with mythical stories, which gradually give place to legends and later emerge into sober history attested by documents, which, if not contemporary, date from a time so near to the events, that their testimony, when tested by general considerations, may be accepted. The scientific method applied to ordinary history is generally accepted quietly by the public, which is usually grateful for the clearer vision of past events which it affords.

It has been inevitable, that in the general progress of knowledge the scientific method should be applied to all existing records, sacred as well as to so-called profane. A part of the movement of modern knowledge consists, accordingly, of the application of the scientific method, generally known as the higher criticism, to the records in the Bible. The application of this method has resulted in the division of scholars into three camps: (1) there are the sincere, conscientious, open-minded, reverent scholars, who believe in the scientific method, who see that the Biblical records cannot be rightly exempted from scientific treatment, and who go about the work with reverence and sanity; (2) there are the reactionaries, who are unable to believe that any Biblical narrative can ever have had any other significance than that which they have always attached to it, and who spend their efforts endeavoring to prove, often by the flimsiest arguments from supposed archaeology, that every Biblical narrative must

be taken by the historian at its face value; (3) there is the mythological, or pseudo-scientific school, which has become enamored of the scientific method from afar, but has never undergone the training in judgment necessary to the application of scientific principles. The members of this school fall into two groups. There are those who, like Winckler, dissolve Solomon and everything before him into forms of Babylonian myths, while others, like Jensen and Zimmern, resolve most of the Biblical characters into myths. Under Jensen's touch every important character of the Old Testament and Apocrypha, as well as Jesus and Paul, become simply forms of the myths of the Gilgamesh epic. In view of the division of scholarship into these three camps, it is clear that a scientific student of history must take his stand with the first group. He cannot refuse to use the scientific method upon sources simply because they are sacred, nor can he exercise the liberty of dissolving into myth events attested by documents that are nearly contemporary with the events described.

The historical student of the sacred records finds, perhaps, his most difficult task the proper appraisement of the patriarchal narratives. Scientific criticism has shown that the records of these narratives have been drawn verbatim from three documents, the earliest of which dates from the ninth century B.C. and the latest from the middle of the fifth pre-Christian century. The demonstration of this is so convincing that it has won the consent of nearly all the scientific experts. There is probably no hypothesis concerning any modern science which commands so nearly the assent of all who can rightly be called experts in the subject as the so-called Graf-Wellhausen hypothesis of the origin of the Pentateuch. The public is sometimes deceived by the cries of those whose hopes are greater than their knowledge; but were the Graf-Wellhausen hypothesis a person, it might adopt the words which Mark Twain is said once to have cabled from Europe to a friend: "The report of my death is greatly exaggerated." The historical student of the patriarchal narratives must, then, take the Graf-Wellhausen hypothesis as his starting point. But let him follow the sound historical maxim and prefer the testimony of the earliest document, he is still in perplexity, for the oldest document, the so-called J document, is at least

three hundred years later than Moses. It is as far removed from Moses as the translators of the Authorized Version are from us, and further removed from Abraham than we are from Columbus and Martin Luther.

The historian may obtain a clue to guide him in his perplexity from a study of Genesis, ch. 10. For example, Gen. 10: 6 states that the sons of Ham were Cush, Mizraim, Put and Canaan. Cush here is the Egyptian *Kesh*, or Nubia. Mizraim is simply the Hebrew word for Egypt. Put is the *Punt* which figures so largely in Egyptian history—the country to the far south whence so many expeditions were sent and from which myrrh, ivory and pigmies were brought. Canaan is the well-known tribe or group of tribes from which the Phœnicians were developed, which also inhabited Palestine and gave it one of the names by which it is still called. It is clear that these names represent, not individuals, but personified tribes or nations. Take Egypt, for example. We now know the outlines of its history back to about 5000 B.C. At that time it consisted of forty-two distinct tribes, who lived so long in separation from one another that their animal totems persisted as the representatives of the gods of the different nomes down to the Roman period. Perhaps as early as 4000 B.C. these nomes, often at war with one another, had been united into the two kingdoms of upper and lower Egypt, but these were not united into a single monarchy until the time of Mena, about 3400 B.C. It is simply impossible that these forty-two tribes were descended from one man. Their gods, customs, sacred animals, and warlike emblems were all different. The further back we push our knowledge of Egypt, the more its constituent parts ramify into a congeries of unrelated atoms. It is only from the point of view of later times that it can be spoken of as one entity. The Biblical writer has accordingly personified a nation. What can be proved for Egypt can also be proved in lesser degree for Nubia.

If now other parts of the chapter be explored the names of many nations and countries appear. Gomer (v. 2) is the *Gamir* of the Assyrians, the Cimmerians of the Greeks; Madai is the Medes; Tubal and Meshech, the tribes *Tabalī* and *Mushkī* of the Assyrian

inscriptions. Javan is the *ιων* of *ἴωνες*, the Ionians. Elisha (v. 4) is the Alashia of the El-Amarna letters, or the Island of Cyprus; Kittim, the *Kiti* or *Kition*, on that island. Tarshish is Tartessos, the Phœnician mining and trading camp in Spain. Similarly in v. 22 Elam, Asshur and Aram are clearly the names of well known countries. In v. 26 most of the persons mentioned are known to be tribes or towns in south Arabia. In v. 15 it is stated that Canaan begat Zidon. Zidon is the city. Its name means "fishing." The name was not derived from a man, but from an industry.

We derive from this chapter, then, partly composed of J material (ninth century) and P material (fifth century) the general principle that patriarchal names are probably not personal names, but are personified tribes, nations, or places. This is in accord with modern Arabian custom. The Arabs make alliances with other tribes under the fiction of kinship, and then to justify the supposed kinship trace their descent from a common ancestor.[1] In combining the personifications of two documentary sources in Genesis 10 confusion has, in at least one case, resulted. To the J writer (v. 8) the Cush who begat Nimrod was the *Kash* of the Babylonian inscriptions, *i. e.*, the Kassites or Cossaeans, who, entering Babylonia from the East, conquered it about 1750 B.C. and established a dynasty that ruled for 576 years. To the P writer of v. 6 Cush was Nubia, as already pointed out. The combination of these narratives by a later editor has made the two Cushes appear to be the same, so that some interpreters, not recognizing the difference, feel compelled to claim that the Assyrians are descended from a Hamitic race.[2]

We are, then, on safe historical ground, if we assume that at least a part of the patriarchal narratives consists of tribal history narrated as the experiences of individual men. To assume that all patriarchal story is tribal history, would be to create for ourselves new difficulties. When once a man, or a supposed man, has caught the popular imagination, tradition frequently attaches to his name

[1] Cf. Sprenger, "Geographie Arabiens" and "Lectures and Essays of W. Robertson Smith," 461. The position set forth in the text is not new. Many scholars have taken it.

[2] See Kyle, "The Deciding Voice of the Monuments in Biblical Criticism," 106.

stories, which were originally told of others. This could, if it were necessary, be illustrated by many examples, but it is unnecessary to occupy space to prove that which is familiar to every investigator of history or legend.

In applying the principle of interpretation drawn from Genesis, ch. 10, it is convenient to begin with the narratives connected with the twelve sons of Jacob. These correspond to the twelve tribes of Israel, and are probably simply personifications of those tribes. These sons are divided by the narratives into four groups, which are said to be respectively the offspring of four mothers. It is natural to suppose that, if these narratives represent tribal history, that there was an alliance between the tribes which composed each group before the groups themselves were formed into a union. Two of the groups are said to be the offspring of full wives of Jacob. These probably joined in an alliance with each other earlier than the two groups which are said to be descended from Jacob's concubines. In Jacob's marriages, then, and the stories of the birth of his children we probably have an outline of the history of the formation of the confederacy of the twelve Israelitish tribes. The nucleus of this confederacy was the tribes which counted their descent from Leah, viz: Reuben, Simeon, Levi, Judah, Issachar, Zebulon. These were the original tribes of Israel. Later were born the sons of Rachel; *i. e.*, the Rachel tribes came into the confederacy after the other six existed as a definite group. The name Leah means wild-cow; the name Rachel, ewe.[3] It has accordingly been suggested that these were simply the animal symbols of the tribes, and that the Leah tribes were cow boys and the Rachel tribes sheep raisers. Others hold that they were not economic, but totemistic, symbols. Whichever alternative is adopted, the interpretation of Leah and Rachel which makes them the symbols of the intertribal alliances is most probable. The application of the name Joseph to two of these tribes, for reasons which will be mentioned later, was probably not made until after the settlement in Palestine. Again the tribe of Benjamin was not differentiated from the other Rachel tribes until after the settlement in Canaan. Benjamin originally

[3] Delitzsch, "Prolegomena," 80. W. R. Smith, "Kinship," 2d ed., 254.

meant "sons of the south" or "southerners," and was given them because they were the southernmost of the Rachel folk. This southern position they occupied in Palestine, but could hardly have held as a nomadic tribe. The tradition that Benjamin is the youngest of Jacob's sons is a recollection of the late development of the tribe.

Similarly, the name Joseph seems to have been attached to the tribes of Ephraim and Manesseh after the settlement in Canaan. The name itself has had an interesting history. A Babylonian business document of the time of the first dynasty of Babylon (2225–1926 B.C.) had for one of its witnesses *Yashub-ilu*,[4] or Joseph-el. Thothmes III, who conquered Palestine and Syria between 1478 and 1447 B.C., records as one of the places which he conquered in Palestine *Ya-sha-p'-ra*,[5] which Eduard Meyer many years ago recognized as Joseph-el. This equivalence is doubted by W. Max Müller, but is, so far as I can see, possible. How did the name of a Babylonian man become attached to a Palestinian city? There was at the time of the first dynasty frequent intercourse between Mesopotamia and Palestine. Documentary evidence of this will be cited below in connection with Abraham. Is it too much to imagine that a Joseph-el migrated, and that his name became attached to a Palestinian city? Not only have we in our own country many places named for men, but modern Palestine affords an example of a village that lost during the nineteenth century its name, *Karyet el-'Ineb*, and substituted for it the name of a famous sheik, *Abu Ghosh*.[6] If in some such way Joseph-el made its way into Palestine and Rachel tribes afterward settled in the region, the shortened form of the name, Joseph, might naturally become the name of their supposed ancestor.

The principle of interpretation gained from Genesis 10 compels us to suppose that the name Joseph came in in some such way, for in the historical period no tribe of Joseph appears. If the investi-

[4] "Cuneiform Texts, etc., in the British Museum," II., 23, 15.

[5] Mittheilung der Vorderasiatische Gesellschaft, 1907, p. 23. Muller thinks it equivalent to *Yesheb-el*, "God dwells." The Babylonian might also be so interpreted. The phonetic equivalence between Babylonian and Hebrew points rather to *Joseph-el*, and the Babylonian form may account for the Egyptian spelling.

[6] See Baedeker's "Palästina," 1910, p. 16.

gator is forced to this conclusion, how are the vivid narratives of the personal fortunes of Joseph to be accounted for?

The archæological discoveries of recent years have made it probable that the Joseph tribes alone were concerned in the Egyptian residence and bondage.[7] The stele of Merneptah,[8] to whom all Biblical indications point as the Pharaoh of the Exodus, clearly shows that Israel, or the Leah tribes, were already in Palestine. The fact that the Ephraimite document, E, recalls as the Judæan document J does not, the revelation of the name Yahweh,[9] and that the ark of the covenant was afterward preserved in an Ephraimite shrine,[10] point in the same direction. If these tribes alone had the Egyptian experience and were at first the sole guardians of the Egyptian tradition, when once they had come to regard Joseph as their ancestor it would be natural for many stories to cluster about his name. In this connection it is an interesting fact that several of the stories told of Joseph are almost identical with other stories and facts which archaeological research have brought to light, but which in their original setting are connected with other names. The chief of these are the following:

1. The story of Joseph's temptation by Potiphar's wife is strikingly parallel to the tale of two brothers—a tale in which the younger brother is subjected by his sister-in-law to the same temptation as Joseph, and, when, like Joseph, he repulses her, she professes to have been outraged by him, and plunges him into misfortune.[11] This story comes to us in a papyrus dated in the reign of Seti II., 1209–1205 B.C., and is accordingly very old.

2. The career of Joseph as ruler of Egypt is paralleled by the career of Dûdu or David, an official bearing a Semitic name, who seems to have held a high position under Amenophis IV. of the eighteenth Egyptian dynasty, before 1350 B.C. In the El-Amarna correspondence two letters addressed to this Dûdu by Aziru, king of the Amorites, occur. They tell their own tale, and are as follows:

[7] See Paton's article, "Israel's Conquest of Canaan," *Journal of Biblical Literature*, XXXII, 1–54.

[8] See Breasted's "Ancient Records, Egypt," III., § 617.

[9] Ex. 3: 13, 14.

[10] I Sam. 3 and 4.

[11] See Petrie's "Egyptian Tales," second series, London, 1895, 36 ff.

I.[12]

[1] To Dûdu, my lord, my father, [2] speaks Aziru, thy son, thy servant: [3] at the feet of my father I fall. [4] Unto my father may there be health! [5] O Dûdu truly I have done [6] the wish of the king, my lord, [7] and whatever is the wish [8] of the king, my lord, let him send [9] and I will do it. [10] Further: see, thou art there, [11] my father, and whatever is the wish [12] of Dûdu, my father, send it [13] and I will do it. [14] Behold thou art my father [15] and my lord and I am thy son. The lands of the Amorites [16] are thy lands, and my house is thy house, [17] and whatever thy wish is, [18] send, and I [19] shall behold and verily will do it. [20] And see, thou in the presence of [21] the king, my lord sittest. [22] . . . enemies [23] words of slander [24] before my father, before [25] the king, my lord, have spoken, [26] but do thou not count them just! [27] And behold thou in the presence [28] of the king, my lord, as a dignitary(?) [29] sittest . . . [30] and the words of slander [31] against me do not count as true. [32] Also I am a servant of the king, my lord, [33] and from the words of the king, my lord, [34] and from the words of Dûdu, my father, [35] I shall not depart forever. [36] But when the king, my lord does not love me, [37] but hates me, [38] then I—what shall I say?

II.[13]

[1] To Dûdu, my lord, my father, [2] speaks Aziru, thy servant: [3] at the feet of my lord I fall. [4] Khatib has come [5] and has brought the words [6] of the king, my lord, important and good, [7] and I am very, very glad, [8] and my lands and my brethren, [9] the servants of the king, my lord, [10] and the servants of Dûdu, my lord, [11] are very, very glad [12] when there comes [13] the breath of the king, my lord, [14] unto me. From the words [15] of my lord, my god, my sun god, [16] and from the words of Dûdu, [17] my lord, I shall not depart. [18] My lord, truly Khatib [19] stands with me. [20] I and he will come. [21] My lord, the king of the Hittites [22] has come into Nukhashshi, [23] so that I cannot come. [24] Would that the king of the Hittites would depart! [25] then, truly, I would come, [26] I and Khatib. [27] May the king, my lord, my words [28] hear! My lord, I fear [29] on account of the face of the king, my lord, [30] and on account of the face of Dûdu. [31] And now by my gods [32] and my messengers verily I have sworn, [33] O Dûdu and nobles [34] of the king, my lord, that truly I will come. [35] And so, Dûdu [36] and the king, my lord, and the nobles, [37] "truly we will not concieve anything [38] against Aziru that is unfavorable"—[39] even thus may ye swear by [40] my gods and the god A'. [41] And truly I [42] and Khatib are faithful servants of the king. [43] O Dûdu, thou shalt truly know [44] that I will come to thee.

In these letters Aziru constantly classes Dûdu with the king. He fears to offend Dûdu as he fears to offend the king. The words of Dûdu he counts as of equal importance to those of the king. Dûdu

[12] Winckler & Abel, "Thoutafelnfund von El-Amarna," No. 40 and Knudtzon's "Die El-Amarna Tafeln," No. 158.

[13] Winckler & Abel, No. 38 and Knudtzon, No. 164.

clearly occupied a position of power with the king similar to that ascribed to Joseph in Genesis.

3. The action of Joseph in storing up corn and then distributing it during a time of famine is paralleled by the course of Baba of El-Kab, who flourished under the eighteenth dynasty of Egypt about 1500 B.C., and who says in an inscription carved in his tomb, at the close of a description of the activities of his life:

> "I collected corn as a friend of the harvest-god. I was watchful in time of sowing. And when a famine arose, lasting many years, I distributed corn to the city each year of the famine."[14]

The principal features of Joseph's life are thus paralleled in ancient history. The careers of Baba and Dûdu are thoroughly historical; our knowledge of them rests upon contemporary documents. While the latter part of the tale of the two brothers contains much that is mythical, the portion which deals with the brother's wife is so natural, and presents such a vivid picture of Egyptian rural life, that there can be little doubt that it is based on a real incident.

When once a name has become prominent in a nation it tends, by a law of human nature, to gather to itself all the appropriate stories known. One heard at Harvard a generation ago stories told of the late Professor Andrew P. Peabody, which a generation before had been told in Germany of the absent-minded Professor Neander. Before our eyes to-day stories are attaching themselves to Colonel Roosevelt which originally were told of others. It is not too much to suppose that the stories known to us from the sources quoted attached themselves to the name of Joseph, and thus filled out to the later Israelites the figure of their shadowy patriarch. This supposition, confirmed by historical and legendary analogies, enables us to find in the Joseph stories real history. It is not, it must be confessed, the history of a real Hebrew patriarch, but it is real history of Egypt and Palestine and of real men in them. The history is recovered, too, by following historical methods and following historical analogies, and relieves us from the necessity of supposing with Winckler that Joseph is but a series of Tammuz myths, or with Jensen, that he is a group of Gilgamesh myths.

[14] Cf. Brugsch, "Egypt under the Pharaohs," London, 1881, I., 303 ff.

Our pursuit of the origin of the Joseph-stories has taken us far afield from the discussion of the tribal history of the patriarchs. The accounts of the marriages of the sons of Judah and of an episode in the life of Judah himself in Genesis 38 may easily be understood to be alliances made by that tribe with clans previously living in their territory. Judah in all the subsequent history stood apart from the other Hebrew tribes. That she formed in David's early reign and after the time of Solomon a separate kingdom was in part due to the larger element of Canaanite blood in her.

Similarly the story in Genesis 34 of Simeon and Levi[15] represents an unsuccessful and treacherous attack of those tribes on the ancient city. In this attack they were practically annihilated and their kinsmen regarded their punishment as just.[16] On the view that the patriarchal stories are adumbrations of tribal history, the traditions which ascribe the birth of the patriarchs Gad, Asher, Dan and Naphtali to slave mothers may indicate that these tribes joined the Israelitish confederacy later than the union between the two great groups of Leah and Rachel tribes. If this were the case, these tribes probably came into the confederacy after the settlement in Palestine, and were, presumably, Amorite or Canaanite tribes who were there already. In the case of the tribe of Asher this supposition receives some confirmation from documents outside the Old Testament.

The father of Aziru, the Amorite, who wrote the letters to Dûdu quoted above, was named Ebed-Ashera, Ashera being a goddess. Ebed-Ashera in his time was in frequent war with Gebal, whose king, Rib-Adda, complained to the king of Egypt in many letters preserved for us in the El-Amarna correspondence. Rib-Adda sometimes calls the people over whom Ebed-Ashera ruled Amorites (Amurru), sometimes the "men of Ebed-Ashera" and often the

[15] The story appears in two forms; one is by J and the other by a priestly writer. In the former Shechem appears on one side and Simeon and Levi on the other; Shechem violates Dinah and the brothers take terrible vengeance upon him. In the latter Hamor, the father of Shechem proposes honorable marriage for his son with Dinah, and all the sons of Jacob are represented as acting as one man. Cf. Carpenter and Harford-Battersby, "Hexateuch," 52 ff.

[16] Gen. 49: 5-7.

"sons of Ebed-Ashera." It would be easy in course of time for the Ebed to drop out and the tribe to be called "sons of Ashera" or "sons of Asher."[17] As this tribe in the period covered by the El-Amarna correspondence (1400–1350 B.C.) was in the same region in which the Hebrew tribe of Asher was afterward settled, it seems probable that the Hebrew tribe was the same as the earlier Amorite tribe. This would fit in well with the conclusion to which the tribal interpretation of Jacob's marriage points.

When the investigation moves back a generation in the patriarchal genealogies, the same principle holds, but new perplexities appear. It is clear that Esau is the personification of the Edomite nation, and Israel that of the nucleus of the Hebrews. Already in the time of Merneptah there was an Israel, which was a nation. Probably it consisted of the Leah tribes. But the Hebrew patriarch is also called Jacob, and most of the stories concerning him are told of him as Jacob. There is reason to believe that the name Jacob had an origin similar to the name Joseph.

In the reign of the Babylonian king, Apil-Sin (2161–2144 B.C.), two witnesses to a contract, Shubna-ilu and Yadakh-ilu gave the name of their father as *Yakub-ilu* or Jacob-el.[18] Another witness, Lamaz, had a Jacob-el as his father.[19] In the reign of the next king, Sin-muballit (2143–2124 B.C.), a witness named Nur-Shamash was the son of *Yakub-ilu,* or Jacob-el,[20] while another witness, Sin-erbiam, gave his father's name simply *Yakub,* or Jacob.[21] Seven hundred years later Thothmes III. records among the names of cities which he conquered in Palestine a city *Ya'ke-b'-ra,*[22] the Egyptian equivalent of Jacob-el. The probability is that some Babylonian who bore the name migrated to the west, and in course of time

[17] See, *e. g.*, Schrader's "Keilinschriftliche Bibliothek," Nos. 53, 54, 55, 56, 57, 59, 60, 62, 63, 64, 68, 69, 70, 71, 73, 75, 76, 77, 78, 83, 84, 86, 88, 91, 92, 101.

[18] "Cuneiform Texts, etc., in the British Museum," IV., 33, 22b.

[19] Meissner, "Altbabylonische Privatrecht," 36, 25.

[20] "Cuneiform Texts," VIII, 25, 22.

[21] "Cuneiform Texts," II., 8, 26.

[22] *Mitteilungen der vorderasiatische Gesellschaft,* 1907, p. 27.

The city seems to have been east of the Jordan and was, perhaps, the same as Penuel, Gen. 32: 31.

a city was named after him. Later, when the Hebrews settled near this city, they took over the name of its hero in shortened form as a name for their eponymous ancestor. All the reasons quoted above for the name Joseph apply here. Apart from stories of marriages and friction with Esau, which denote tribal relations, the one important tale connected with Jacob is his dream at Bethel. This was one of the stories by which the Hebrews justified to themselves their adoption of an old Canaanitish shrine. The stories of Isaac seem, in like manner, to be tales of alliance with Aramaeans, and tales of shrines like that at Beersheba. We have no extra Biblical material with which to compare them.

When the investigator takes up the stories of Abraham, moving back still a generation from the nation Israel, he is confronted with much material and with a wealth of conflicting theories. Of course to Jensen Abraham is a form of the Gilgamesh myth.[23] To Winckler and Zimmern Abraham is a moon god. The reasons for this latter view have seemed convincing to many. Abram, of which Abraham was but a variant form, has been held to be of West Semitic origin and to mean "exalted father."[24] It is really, as we shall see, of Babylonian origin and has another meaning. Tradition connects him with Harran and Ur, both seats of the worship of the moon god. In Babylonian hymns Sin, the moon god, is frequently called *Ab* or father.[25] Sarah or Sarai, the name of Abraham's wife, is the Hebrew equivalent of *šarratu*, "queen," an epithet of the consort of the moon god at Harran. Milcah, Abraham's sister-in-law (Gen. 11 : 29), is *Malkatu*, the name of a consort of the sun god and perhaps also of the moon god.[26] These are some of the arguments which seem to the adherents of this view conclusive. It must be confessed that many of the stories told of Abraham in Genesis are connected with shrines, and would be explicable on this view. Their purpose was undoubtedly to justify the use by Hebrews of the shrines of Shechem, Bethel, Hebron, and Beersheba. This is not, however, the whole of the matter. We have now evidence that

[23] "Gilgameshepos und der Weltliteratur," I., 256 ff.

[24] Briggs, Brown and Driver, "Hebrew Lexicon," 4.

[25] Cf. *Journal of Biblical Literature*, XXVIII., p. 166, n. 26.

[26] Schrader, "Keilinschriften und das Alte Testament," 3d ed., 364 ff.

Abraham was in Babylonia a personal name. This evidence comes from Dilbad, a little place about eight miles south of Borsippa, and consists of some contracts in which an Abraham figures. Three of the documents are here translated:

I.[27]

[1]1 ox, broken to the yoke, [2]an ox of Ibni-Sin son of Sin-imgurani, [3]from Ibni-Sin [4]through the agency of Kishti-Nabium, [5]son of Eteru, [6]Abarama, son of Awel-Ishtar, [7]for 1 month has hired. [8]For 1 month [9]1 shekel of silver [10]he will pay. [11]Of it ½ shekel of silver [12]from the hand of [13]Abarama [14]Kishti-Nabium [15]has received.

The names of the witnesses then follow and the date, which is the 11th year of Ammizadugga, or 1967 B. C.

II.[28]

[1]To the patrician [2]speak [3]saying, Gimil-Marduk (wishes that) [4]Shamash and Marduk may give thee health! [5]Mayest thou have peace, mayest thou have health! [6]May the god who protects thee [7]keep thy head in good luck! (To inquire) [8]concerning thy health I am sending. [9]May thy welfare before Shamash and Marduk [10]be eternal! [11]Concerning the 400 *shars* of land, the field of Sin-idinam, [12]which to Abarama, [13]to lease, thou hast sent; [14]the land-steward and scribe [15]appeared and [16]on behalf of Sin-idinam [17]I took that up. [18]The 400 *shars* of land to Abarama [19]as thou hast directed [20]I have leased. [21]Concerning thy dispatches I shall not be negligent.

III.[29]

[1]1 shekel of silver, [2]the rent of his field [3]for the year that Ammizadugga, the king, (set up) [4]a lordly, splendid statue (*i. e.* Ammizadugga's 13th year), [5]brought [6]Abarama; [7]received (it) [8]Sin-idinam [9]and Iddatum. [10]Month Siman, (May–June) 28th day, [11]the year Ammizadugga, the king (set up) [12]a lordly, splendid statue.

These documents are conclusive proof that Abarama, or Abraham, was a personal name in Babylonia. The name apparently meant, "He (*i. e.*, some god) loves the father." The Abraham revealed in these documents was not the patriarch, but was a small farmer in Babylonia. His father was Awel-Ishtar, not Terah; his brother, Iddatum, not Nahor. His existence, however, shows that, just as

[27] *Vorderasiatische Schriftdenkmäler der königliche Museen zu Berlin*, VII., No. 92.

[28] *Ibid.*, No. 198.

[29] *Ibid.*, No. 97.

in the cases of Jacob and Joseph, a living person probably existed far back in history about whose name stories, gathered from various quarters, afterward clustered.

That such a person may have migrated from Babylonia to Palestine, as the Biblical patriarch is said to have done, is clearly attested by an interesting little contract from Sippar, which reads as follows:[30]

[1]A wagon [2]from Mannum-balum-Shamash, [3]son of Shelibia, [4]Khabilkinum, [5]son of Appanibi [6]on a lease [7]for 1 year [8]has hired. [9]As a yearly rental [10]2/3 of a shekel of silver [11]he shall pay. [12]As the first of the rent [13]1/6 of a shekel of silver [14]he has received. [15]Unto the land of Kittim [16]he shall not drive it. (After the names of the witnesses comes the date.) [22]Month Ulul, day 25th, [23]the year the king as a friend protected Erech from the flood of the river.

The date of this interesting document has not been identified with certainty, but it probably comes from the reign of Shamsuiluna (2080–2043 B.C.). The country Kittim mentioned in it is the Mediterranean coast, which was sometimes so called by the Hebrews (cf. Isa. 2:10, and Eze. 27:6). The interesting thing is that intercourse between the Babylonian city of Sippar and the Mediterranean coast was so frequent when this contract was made, that a man could not lease his wagon for a year without running the risk that it might be driven to the Mediterranean coast lands. It was in a period of such frequent intercourse that some Joseph-el and Jacob-el migrated from Babylonia and gave their names to Palestinian cities. And it would seem that some Babylonian Abraham may have done the same, for Sheshonk I., of the twenty-second Egyptian dynasty (the Shishak of the Bible), records as one of the places captured by him in Palestine a place called "The field of Abram."[31] This place would seem to have been in southern Judah. It would seem quite as likely that a Babylonian Abraham may have given his name to the place in the same way that a Jacob-el and a Joseph-el did, and that, after Hebrews had settled in the country, they took his name over, just as they did the other two, as to suppose that the name Abraham originated in an epithet of a moon god.

One cannot well refuse to believe that many of the stories con-

[30] See *Beitrage zur Assyriologie*, V., p. 488, No. 23; cf. p. 429 ff.

[31] See Breasted, "Ancient Records, Egypt," IV., 352, 353.

nected with Abraham grew up in Palestine around certain shrines. They were the instruments by which Israel justified her use of these shrines. Other stories, like that in Genesis 18, 19, arose as the explanation of natural phenomena, such as the existence of the impressive gorge of the Dead Sea, and probably in their earliest form had no connection with Abraham. One can hardly believe, in view of all the evidence presented, that Abraham was the real ancestor of all the peoples said to be descended from him, any more than he can believe that all Egyptians were descended from one, Mizraim, but it is no longer unthinkable that the stories collected about Abraham have been attached to the name of a real man, who once migrated from Babylonia.

This paper cannot conclude without some remarks about the historical character of the fourteenth chapter of Genesis. Critics agree that it does not belong to either of the four great documents of the Hexateuch, and a considerable unanimity of critical opinion has been reached in recent decades, that it is later than all of them, and that it is a kind of Jewish midrash of a thoroughly unhistorical character. On the other hand, a large group of conservative scholars have endeavored to show from Babylonian texts that it is real history—history the authenticity of which is confirmed by the monuments. What are the facts as they appear to an unprejudiced mind? They are as follows:

Hammurapi, the great Babylonian lawgiver, one of the most important of all the Babylonian kings, reigned from 2123 to 2081 B.C., and claimed sovereignty of *Mar-tu*, or the Westland, probably Syria and Palestine. Many scholars have held that Hammurapi was the same as Amraphel of Gen. 14: 1. The names would exactly correspond were it not for the *l* at the end of Amraphel. By no known philological equivalence does that letter belong there, and if Hammurapi is intended by Amraphel, Gen. 14 must have been written so late that the name had become corrupted in a way similar to the corruption from which good Hebrew names have suffered in the angelic lists of the Ethiopic Enoch.[32]

[32] See the writer's article, "Origin of the names of Angels and Demons in the Extra-Canonical Apocalyptic Literature to 100 A. D." in *Journal of Biblical Literature*, XXXI., 156 ff.

Arioch, king of Elassar (Gen. 14: 1), has been identified with Rim-Sin, king of Larsa, a contemporary of the latter part of the reign of Hammurapi. But the fact is the name of Rim-Sin could not even in Sumerian possibly be read Ari-aku. That of his brother, Arad-Sin, might be so read, but there is nothing to lead us to suppose that it was, and there is no evidence that either Arad-Sin or Rim-Sin were ever in friendly alliance with Hammurapi.[33]

Again, much has been made of the fact that Kudur-Mabug, the father of Arad-Sin and Rim-Sin, who was the "Ad-da" or ruler of Emutbal, a district of western Elam, calls himself "Ad-da" of *Mar-tu*,[34] which has been supposed to be Palestine. *Mar-tu*, however, simply meant the place of sunset, and probably in this inscription refers to the western part of Elam.[35] There is really nothing whatever to connect Kudur-Mabug with Palestine at all. And even if there were, his name is not Cherdorlaomar, so that again the inscription would be evidence of the lack of information on the part of the Biblical writer.

Much has been made by Professors Sayce[36] and Hommel of four documents published by Pinches in the *Transactions of the Victoria Institute*, XXIX., 82 ff., which, according to Sayce and Pinches, contain the names of Arioch, Cherdorlaomar, and Tidal, the three kings, who in Gen. 14: 1 are associated with Amraphel. The documents are written in Semitic and are from the Persian period, not earlier than the fourth century B.C.

In reality neither the names Cherdorlaomar nor Arioch appear in the text. The name read Kudurlakhmal is really *Ku-ku-ku-mal* or *Ku-dur-ku-mal*. The other reading is only obtained by giving to the sign *ku* a value, *lakh*, altogether unattested by the cuneiform literature. The name read Eri-eaku and identified with Arioch is spelled in two ways. If read as Sumerian, it might be Eri-eaku. The text in which it occurs is, however, Semitic, and it is probable that the name is to be read here in Semitic fashion. So read it

[33] Cf. *Journal of Biblical Literature*, XXVIII., 158 ff.

[34] "Cuneiform Texts," XXI., 33.

[35] See Price, Decennial Publications of the University of Chicago, V., 167 ff.

[36] Cf. PSBA. XXVIII., 203–218, 241–251; XXIX., 7–17. Cf. also King, "Letters and Inscriptions of Hammurabi," I., p. li ff.

becomes Arad-malkua, or Arad-malaku. Tudkhula, the supposed Tidal, is not called in the document a king at all. To identify him with "Tidal, king of the nations," is a purely fanciful procedure.

It should be noted that in the documents which record these names Arad-malaku, the supposed Eri-aku, takes no part in the wars described; it is his son, Dursil-ilâni (who, by the way, has a good Semitic name) who is represented as the contemporary of Kukukumal, the supposed Cherdorlaomar. It should be further noted, that these documents represent a complete conquest of Babylon by Elam—a conquest so complete that:

> "In their faithful counsel unto Kukukumal, king of Elam,
> They [the gods] established the fixed advance, which to them seemed good.
> "In Babylon, the city of the gods, Marduk set his [Kukukumal's] throne,
> All, even the Sodomites of the plundered temples, obey him.
> Ravens build their nests; birds dwell [therein];
> The ravens croak(?), shrieking they hatch their young [in it].
> To the dog crunching the bone the Lady . . . is favorable.
> The snake hisses, the evil one spits poison."

This quotation from the second of the documents published by Pinches describes a complete subjugation and desolation of Babylon by Kukukumal, king of Elam. This definitely excludes the possibility that Kukukumal could have acted in harmony with Hammurapi, as Cherdorlaomar is said to have done. Indeed, it shows that he was not a contemporary of Hammurapi at all, for during his powerful reign there was no such conquest of Babylon by Elam. There were many conquests of Babylonia by the Elamites, and this must refer to some other period. In the documents themselves there is evidence that another period is intended, for Babylon is called by its Cassite name, Kar-duniash, a name that it did not bear until three or four hundred years after Hammurapi.

If the fourteenth chapter of Genesis was influenced at all by these documents, it is only another proof that the critics have been right, and that the chapter is not an authority as history.

Bryn Mawr College,
April 17, 1913.

THE DETERMINATION OF URANIUM AND VANADIUM IN THE CARNOTITE ORES OF COLORADO AND UTAH.

By ANDREW A. BLAIR.

(Read April 17, 1913.)

The determination of uranium in ores has become a matter of importance, due to the discovery of ores containing this element in Colorado and Utah and the constantly increasing demand for them. In these ores the uranium is associated with two to four times as much vanadium and varying amounts of silica, alumina, oxide of iron, lime and magnesia. They are practically free from phosphoric acid and sulphides, and contain very small amounts of metals precipitated by hydrogen sulphide in an acid solution. The problem thus is practically the separation of the uranium and vanadium from the alumina and oxide of iron, and their separation from each other. The first part of the problem is readily solved by the use of ammonium carbonate, which dissolves the uranium and vanadium and precipitates the oxide of iron and alumina. The separation of uranium from vanadium is more difficult, owing to the strong affinity between these elements. The volumetric method seems to offer an ideal separation as hydrochloric acid reduces the vanadium to the vanadyl condition without affecting the state of oxidation of the uranium and subsequent evaporation with sulphuric acid and titration with permanganate gives an accurate method for the determination of the vanadium. Subsequent reduction by aluminum reduces the uranium to UO_2, but it also reduces the vanadium theoretically to the state of V_2O_2, but upon the removal of the aluminum the vanadium absorbs oxygen so quickly that the actual state of oxidation is uncertain and the titration becomes unreliable. In Low's "Technical Methods of Ore Analysis," page 204, the method relies on the precipitation of the vanadium as lead vanadate in the presence of free acetic acid for its separation from the uranium, and while with great care this may be accomplished with more or less

accuracy it leaves much to be desired in the way of simplicity and ease of manipulation.

The method given by Carnot[1] for the determination of vanadium by adding uranyl nitrate and precipitating the ammonium uranyl vanadate in a solution slightly acid with acetic acid lends itself admirably to the reverse determination, and in the presence of an excess of vanadic acid the uranium may be accurately and easily determined.

Ammonium uranyl vanadate is a canary yellow flocculent precipitate resembling sulphide of arsenic. It settles rapidly and is quite insoluble in a solution faintly acid with acetic acid. It must be washed with a hot solution containing about 5 c.c. of slightly acid ammonium acetate to 100 c.c. of water, as it is slightly decomposed by pure water, passes through the filter and is reprecipitated in the filtrate. Upon ignition the V_2O_5, $2UO_3(NH_4)_2O + H_2O$ loses ammonia and water and becomes V_2O_5, $2UO_3$. It burns readily, but should not be heated above a low red, as it fuses and becomes very insoluble. Even when not fused it dissolves with difficulty in a large excess of dilute nitric acid. Fusing the salt does not appear to change its composition or the degree of oxidation of the uranium as the weight remains constant. When fused, a little hydrofluoric acid added to the dilute nitric acid causes it to dissolve more readily.

Determination of Uranium.

Boil two grammes of the finely ground ore with 25 c.c. of strong nitric acid and 25 c.c. water for half an hour, dilute and filter. Reject the insoluble portion. Neutralize the filtrate with ammonia and after a precipitate has formed add a strong solution of ammonium carbonate in excess. A large excess of ammonium carbonate is to be avoided as it dissolves appreciable amounts of both alumina and oxide of iron. This precipitates the alumina, oxide of iron, etc., while the uranium and vanadium are dissolved. The volume of the solution should be about 250 c.c. The solution should be warm but not hot, 40°–50° C. is a good temperature. Stir constantly for fifteen or twenty minutes and allow the precipitate to settle. Decant as much as possible of the clear liquid on the filter, and finally pour

[1] "Traité d'Analyse des Substances Minerales," Vol. II, p. 791.

on the precipitate and wash it two or three times with water containing two grammes of ammonium carbonate to the 100 c.c. Evaporate the filtrate. Dissolve the precipitate in a small quantity of hot dilute nitric acid and reprecipitate as before. Filter and add the filtrate to the first one. Evaporate until the ammonium carbonate is expelled and acidulate with a few drops of nitric acid. Evaporate until the volume of the solution is about 200 c.c., transfer to a 400-c.c. beaker, and add ammonia until a precipitate appears. Add nitric acid drop by drop until the solution clears, then add 10 to 15 c.c. of ammonium acetate, made by adding 30 per cent. acetic acid to strong ammonia until the liquid is acid to litmus paper. This will require a little over three volumes of acetic acid to one volume of ammonia. The precipitate which forms immediately is the ammonium uranyl vanadate V_2O_5, $2UO_3$, $(NH_4)_2O + H_2O$, mentioned by Carnot. After boiling for a few minutes it settles rapidly, leaving a clear supernatant liquid. Decant the clear liquid on a filter and wash twice by decantation with hot water containing 5 c.c. of the ammonium acetate mentioned above to 100 c.c. of water. Wash the precipitate onto the filter and wash several times with the same solution. Dissolve the precipitate adhering to the beaker in hot dilute nitric acid, pour it on the filter allowing the solution to run into a small beaker. Wash the filter with dilute nitric acid and hot water and evaporate the solution to dryness, without heating above water bath temperature. Dissolve in a little hot dilute nitric acid and add ammonia until a precipitate forms, then ammonium carbonate to dissolve the uranium and vanadium and precipitate any alumina and silica. Allow to stand until the precipitate settles, filter, wash with ammonium carbonate, acidulate the filtrate with nitric acid, boil off the carbonic acid and precipitate by ammonia and ammonium acetate as above. Filter, wash, ignite at a low red heat and weigh as V_2O_5, $2UO_3$, which contains 74.48 per cent of U_3O_8.

The success of this method depends on the presence of more than a sufficient amount of vanadic acid to form a precipitate of the composition mentioned, and this is the case with all the ores I have seen from these localities. It is well, however, to make sure of this and therefore the filtrate from the first precipitation of ammonium uranyl vanadate should be acidulated with nitric acid and a few

drops of hydrogen peroxide added. If the liquid becomes brownish yellow in color it shows an excess of vanadic acid. If it does not it is better to take a fresh portion and add a solution of vanadic acid in nitric acid. The amount to be added can be judged by the appearance of the precipitate of ammonium uranyl vanadate formed in the first instance.

Second Method for the Determination of Uranium.

In the presence of large amounts of alumina and oxide of iron an extremely accurate separation of uranium may be made by using the reaction suggested by Gooch & Havens,[2] by which aluminum chloride is precipitated in a crystalline form free from iron in a solution of equal parts of ether and the strongest hydrochloric acid saturated with hydrochloric acid gas. Havens[3] has shown that this method gives a separation of alumina from beryllium, zinc, copper, mercury and bismuth. I have found that it gives an excellent separation from uranium and vanadium and the method as worked out is as follows:

Treat two grammes of ore as directed in the method described above for the determination of vanadium and after evaporating the hydrochloric acid solution to syrupy consistency, transfer it to a narrow graduated beaker of about 100 c.c. capacity, using concentrated hydrochloric acid to wash all the solution from the larger beaker. The liquid should not exceed 20 c.c. to 25 c.c. in volume. Cool the liquid to about 15° C., and saturate it at that temperature with hydrochloric acid gas. The gas may be generated from rock salt or ammonium chloride in lumps and strong sulphuric acid and the current of gas should be constant and of considerable volume.

When the gas is no longer absorbed but passes freely through the liquid in the beaker note the volume and add an equal volume of ether. Saturation of the liquid generally increases the volume about one fifth and to obtain a satisfactory separation of alumina the volume of ether added should equal the volume of the saturated solution. Continue passing the gas until the solution is again saturated, being careful to keep the temperature of the solution close

[2] Gooch, "Methods of Chemical Analysis," p. 204.

[3] *Loc. cit.*, pp. 216, 217.

to 15° C. Hydrous aluminum chloride is precipitated together with lead chloride, while iron, uranium, vanadium, etc., remain in solution. Prepare an equal volume of hydrochloric acid and ether saturated as described above at 15° C. to wash the precipitate of aluminum chloride.

Filter on a Gooch crucible, allowing the solution to run into a beaker in a bell-jar and wash with the prepared solution. Heat the filtrate and washings carefully, evaporate to syrupy consistency and make an ether separation in the usual way. The ethereal solution contains the ferric chloride and any molybdenum that may be in the ore, while the acid solution contains the uranium, vanadium, lime, etc. Evaporate the solution nearly to dryness, replace the hydrochloric acid by nitric acid, and evaporate to dryness at water bath temperature. This oxidizes the vanadium and uranium to the vanadic and uranic conditions. Add a few drops of nitric acid and dilute the solution, add ammonia until a permanent precipitate forms, then excess of ammonium carbonate to dissolve the uranium and vanadium, and filter to get rid of any small amounts of alumina, and oxide of iron that may not have been removed by the operations described above. Determine the uranium as described in the first method as uranyl vanadate.

Determination of Vanadium.

Boil 2 grammes of the finely ground ore with 10 c.c. of nitric acid and 10 c.c. of water, add hydrochloric acid in excess, evaporate to dryness, redissolve in hydrochloric acid, dilute and filter. Reject the insoluble matter. Evaporate the filtrate to syrupy consistency and make an ether separation to get rid of the iron. Evaporate the hydrochloric acid solution very low, add 25 c.c. or 30 c.c. hydrochloric acid and repeat the evaporation several times to insure the reduction of the vanadium to vanadyl chloride. Add 5 c.c. strong sulphuric acid and evaporate until fumes of sulphuric acid are given off. Cool, dissolve in water, and titrate at a temperature of about 60°–70° C. with permanganate solution in a volume of about 100 c.c. The iron factor of the permanganate multiplied by 1.6342 gives the V_2O_5, taking vanadium as 51.0.

Philadelphia, April, 1913.

SUETONIUS AND HIS BIOGRAPHIES.

By JOHN C. ROLFE.

(*Read April 17, 1913.*)

Suetonius' "Lives of the Cæsars" is a work which is less well known to us than it ought to be. Its frequent citation in historical writings and in treatises on Roman antiquities might seem to make this statement a questionable one, but it is justified both by the rarity of the appearance of the author in our college courses of study, and by the publication of so few editions of the "Cæsars" or of individual lives in English; while no full and satisfactory commentary exists in any language, so far as I know.

The work has the unusual distinction of three *editiones principes*, of which two appeared in Rome in 1470 within a few months, and one in Venice the year following. Between that date and 1820 more than forty editions were issued, including some reprints, under the names of such scholars as Erasmus, Stephanus, Casaubon, Burmann and Ernesti. Bentley commenced an epoch-making edition which was never finished, and between 1606 and 1796 three translations into English were made.

Since 1820 the publications dealing with the "Cæsars" have been relatively few. In 1858 C. L. Roth issued a text which was the standard until 1906, when L. Preud'homme published a new recension, followed the next year by that of M. Ihm. No commentary on the entire work has been made since that of Baumgarten-Crusius in 1816, several times reprinted and with some additions by Hase (Paris, 1826). This is naturally not up to date, besides being far from complete. In English we have had editions of the "Julius and Augustus,"[1] the "Augustus,"[2] and "Tiberius-Nero,"[3] and com-

[1] H. T. Peck, New York, 1893^2.

[2] E. S. Shuckburgh, Cambridge (England), 1896.

[3] J. B. Pike, Boston, 1903.

mentaries on "Claudius"[4] and "Galba-Vitellius"[5] have been published abroad. Ihm seems to have had a full commentary in mind, but the appearance of this, as well as of his new text of the fragments, has been delayed, if not prevented, by his untimely death. A survey of the philological journals, both in English and in foreign languages, shows few articles dealing with Suetonius, compared with the number of those devoted to the text and elucidation of many other Roman writers.

The neglect of an author once so popular may be attributed in the main to two causes: first, to a more critical attitude towards the Roman writers as regards their style and a tendency to restrict the reading of the modern student to those which are rated as "classical" in the restricted sense of the term; and secondly, to a more rigorous standard in historical investigation, which has thrown discredit on Suetonius as a source.

While Suetonius must be condemned on both these counts, there are reasons which make the relegation of his biographies to comparative obscurity unfortunate. They are a mine of information on public and private antiquities, they are of surpassing interest for their wealth of anecdote and curious detail, and they are an important representative of a branch of ancient literature of which few examples have come down to us.

The vogue of Suetonius in still earlier days than those of the printed editions is shown by the great number of existing manuscripts, which are counted by hundreds. These are all apparently derived from a single survival, which formed a part of the library at Fulda in 844, as we know from a letter of Servatus Lupus,[6] abbot of Ferrières, at whose request a copy was sent to France and extensively copied. The original *codex Fuldensis* has since been lost.

As in the case of Horace, a multiplicity of manuscripts has rather added to the difficulties of editors than favored their attempts to establish a standard text. The greater number belong to the fourteenth and fifteen centuries, and are suspected of containing the cor-

[4] H. Smilda, Groningen, 1896.

[5] C. Hofstee, Groningen, 1898.

[6] L. Traube, *Neues Archiv der Gesellschaft für ältere Deutsche Geschichtskunde,* XXVII., pp. 266 ff.; cf. *Hermes,* XL., p. 179.

rections and interpolations of the scholars of that period. The emendation of a text disfigured by lacunæ and errors began in fact at an earlier period and had tended to disguise the readings of the archetype as early as the twelfth century.

We have a few manuscripts of admitted superiority, the *Memmianus* of the ninth century, the *Gudianus* of the twelfth, and *Vaticanus 1904*, of about the same date as the latter, but unfortunately coming to an end in the third chapter of the "Life of Caligula." Of these the first is comparatively free from emendations, but it has numerous errors and lacunæ, including the extensive gap at the beginning of the "Life of Julius." The missing portion of this "Life" was apparently still in existence in the sixth century, when Johannes Lydus used a codex[7] containing the missing dedication to C. Septicius Clarus, prefect of the prætorian guard, and hence presumably the opening chapters of the "Life of Julius." These must therefore have disappeared between the sixth and the ninth centuries. To the evidence for their existence, which has been questioned by some, we may add a statement of the commentator Servius[8]; "Suetonius ait in vita Cæsaris responsa esse data per totum orbem nasci invictum imperatorem." This remark, if we may trust Servius for its genuineness, must have been made in the missing portion of the "Life of Julius." Moreover, the general plan of the biographies obliges us to assume a lacuna, and the arguments against it are wholly unconvincing.

The rest of the manuscripts fall into two classes, each represented by numerous codices, of which the second contains more errors and emendations than the first. Individually the manuscripts are of comparatively little value, but their archetypes, whose readings may be recovered from their agreement, are more important, especially that of the first class, which seems to be derived from the same original as the *Vaticanus*.

There is comparatively little difference of opinion as to the value and relationship of the earlier manuscripts. Ihm and Preud'homme, as the result of careful and independent investigations, arrived at

[7] "De Magistr.," 2, 6, p. 102 Fuss.
[8] On Verg. "Æn.," VI., 799.

substantially the same conclusions, and while they differ in their estimate of the relative importance of some few codices, their texts show very slight and unimportant variations one from the other. We might therefore regard the text of Suetonius' "Cæsars" as settled, barring the possibility of the discovery of new material, were it not for the difference of opinion as to the independent value of the later manuscripts.

These codices frequently offer readings superior to those of the earlier ones, but, as has been said, it is suspected that they are the corrections of scholars of the fourteenth and fifteenth centuries and hence of no weight in determining the readings of an archetype. This conclusion was reached by Roth in 1858, but it has since been called in question by various scholars.[9] At present, however, the weight of evidence is on Roth's side, since Ihm and Preud'homme have arrived at the some conclusion through more extensive and thorough studies[10] than have as yet been made public by the supporters of the contrary view. As a matter of fact, except for greater conservatism in the later editions, which is in accord with the current conception of textual criticism, and greater reserve in filling lacunæ, the texts of Ihm and Preud'homme show remarkably few deviations from that of Roth, so that any radical changes must be the result of the demonstration of the independent value of the later manuscripts or of the discovery of fresh material.

As to Suetonius himself our information is somewhat scanty, since he is one of many Roman writers who make few allusions to themselves; in fact the character of his work is not such as to call for revelations of that kind. What we do know is derived for the most part from the "Letters" of the younger Pliny, to whom we

[9] Chr. Modderman, "Lectiones Suetonianæ," Groningen, 1892; H. N. Veldhuis, "Annotationes Criticæ," Leyden, 1897; C. L. Smith, *Harvard Studies in Class. Phil.*, XII. (1901), pp. 54 ff.; A. A. Howard, *id.*, pp. 261 ff.; and others.

[10] Preud'homme, "Première, deuxième, troisième étude sur l'histoire du texte de Suétone de vita Cæsarum," in the *Bulletins de l'Académie royale de Belgique*, 1902, and *Mémoires couronés et autres mémoires publiés par l'Académie royale de Belgique*, LXIII., pp. 1–94; Ihm, *Hermes*, XXXVII., pp. 690 ff. and the introd. to his edition, Leipzig, 1907.

also owe information about his uncle, the elder Pliny,[11] Silius Italicus,[12] Martial,[13] and other writers of the day. C. Suetonius Tranquillus, as he himself tells us,[14] was the son of Suetonius Laetus, a Roman knight, who in April of the year 69, as tribune of the Thirteenth Legion, took part in the battle of Betriacum, where Otho's forces were defeated by those of his rival Vitellius. In other casual allusions of a personal nature, four in number,[15] Suetonius gives us no additional information of importance, although they are of some help in drawing conclusions as to the date of his birth.

His birthplace is unknown. Arguing *ex silentio,* it is possible to infer that he was one of the few Roman writers who were born in the city itself.[16] The dates of his birth and death are also uncertain. The former is assigned by Mommsen[17] to the year 77; by Macé with somewhat greater probability to 69.[18] To determine the exact year is impossible, but the facts of his life, so far as we know them, point to the beginning of the reign of Vespasian. The date of his death is equally uncertain. Our last reference to him as still living is in the year 121, but the implication in one of Pliny's letters[19] that he was slow to publish, taken in connection with the long list of his writings, would seem to indicate that he must have lived to a good old age, including a part of the reign of Antoninus Pius.

From another of Pliny's letters, a reply to a request to have a suit in which his friend is about to plead postponed in consequence of an unfavorable dream,[20] we learn that Suetonius practised at the

[11] III., 5; VI., 16 and 20.

[12] III., 7.

[13] III., 21.

[14] Otho, 10, 1.

[15] Calig., 19, 2; Domit., 12; Nero, 57, 2; cum post viginti annos (after Nero's death), adulescente me, extitisset condicionis incertae qui se Neronem esse iactaret; Gr. 4.

[16] The number of these is at most small, and there is no writer of prominence about whom it can be asserted positively; it is probable in the cases of Cæsar, Lucretius and Suetonius; cf. Macé, "Essai sur Suétone," Paris, 1900, pp. 33 ff.

[17] *Hermes,* III., p. 43.

[18] *L. c.,* pp. 35 ff.

[19] V., 10.

[20] I., 18.

bar, at least for a short time. From a third reference of Pliny[21] Macé and others have assumed that Suetonius was a teacher, and the former, with the imagination characteristic of French scholarship, constantly refers to him as a "maitre d'écôle" and draws inferences from his profession. But the most natural interpretation of *dominis scholasticis* in the passage in question is "scholars turned land-holders," and there seems to be no evidence whatever that Suetonius was a schoolmaster.

Pliny's acquaintance with Suetonius was evidently an intimate one, since he twice refers to him as *contubernalis*.[22] This term, too, seems to imply that the two men were of approximately the same age and hence to support the view that Suetonius was born as early as the year 70. An equality in years is not inconsistent with the reverence[23] which he felt for his distinguished friend, whose position was so much higher than his own, and it is in accord with "Epist.," IX., 34, in which Pliny consults Suetonius as to the advisability of reading his verses in public.

Suetonius held no official position in his earlier years. Through Pliny's good offices he secured a military tribunate,[24] but soon had it transferred to a relative, Caesennius Silvanus. The same good friend secured for him the *ius trium liberorum* from Trajan,[25] although this privilege was not justified by the number of his offspring. That his marriage was unhappy, as well as unfruitful (*parum felix*), is a pure inference. Pliny himself was childless, though he too received the *ius trium liberorum* from Trajan[26]; but the happiness of his wedded life is apparent from several of his letters.[27]

The letters of Pliny which refer to Suetonius cover approximately the period from 96 to 112. When we next hear of him,[28]

[21] I., 24, 4.

[22] I., 24, 1; cf. X., 94, 1.

[23] III., 8, 1: reverentia quam mihi præstas.

[24] III., 8.

[25] X., 94, 95. The lex Papia Poppæa deprived childless men of one half of the legacies and inheritances left them, which made the *ius trium liberorum* particularly in demand.

[26] X., 2.

[27] IV., 19; VI., 4, 7; VII., 5; VIII., 10.

[28] Spartianus, "Vit. Hadr.," 11, 3.

he is holding the responsible position of secretary under Hadrian (*Ab epistulis*, referred to by Spartianus by the later title of *epistularum Magister*). It is altogether probable that he owed this position to the influence of his friend and patron C. Septicius Clarus, to whom he dedicated the "Lives of the Cæsars," and that he held it while Septicius was prefect of the praetorian guard, from 119 to 121. Spartianus tells us in the same passage that both Suetonius and Septicius were dismissed by Hadrian, "quod apud Sabinam uxorem iniussu eius familiarius tunc se egerant quam reverentia domus aulicae postulabat." While this statement is far from definite, the words *iniussu eius* certainly imply some violation of court etiquette rather than any more serious misconduct. After this we lose sight of Suetonius, but it seems probable that he lived in retirement and devoted himself to study and publication.

Our references give us the impression of a man of quiet, scholarly tastes and habits, of no great ambition in other directions, who enjoyed the friendship of a number of distinguished men and from his connection with them and his position under Hadrian had the opportunity of gathering a great amount of information. This is confirmed by the allusions to his works, which are considerably more numerous, as well as by his reputation in later times. According to the fashion of his later years, when the greater part of his books were published, he seems to have written in Greek as well as Latin, although the fact that the titles of some of his works are known to us only in their Greek form is due to the sources in which they have been preserved. The lexicographer Suidas, of the tenth century, has given us a catalogue of his writings,[29] which has been supplemented from other sources,[30] while other references throw some light on the extent and interrelation of some of the books.[31] They are in the general fields of history (biography), antiquities, natural

[29] *S. v.* Τράγκυλλος

[30] Ps. Aur. Vict., "Epit.," 14; Servius on "Æn.," VII., 627; Lydus, "De Magistr.," 3. 64, p. 268 Fuss; Auson., "Ep.," 19, p. 180 Schenkl; Charisius, "Gr. Lat.," I., 236, 17 K.; etc.

[31] Isidore, "De Nat. Rerum," 38 and 44; Priscian, VIII., 20 and 21, XVIII., 149.

history and grammar, and comprise eighteen titles, which are variously arranged by different scholars.[32]

Of all these works only the "Lives of the Cæsars" has come down to us practically entire.[33] We have besides considerable portions of the "De Viris Illustribus," biographies of illustrious Romans in the fields of literature and philology, and numerous detached fragments from other books, preserved in the form of citations and excerpts by later writers.

While the historian of Latin literature can hardly class Suetonius higher than second rate, his influence was greater than that of many more eminent writers, partly because of his relatively high rank in the period of his activity, but especially because his "Lives of the Cæsars" appealed to the spirit of the age. Because of this they gave a biographical turn to historical writing which endured for centuries. They served as a model for Marius Maximus, who lived from about 165 to 230, and for the writers of the Augustan History ("Scriptores Historiæ Augustæ") of the time of Diocletian and Constantine, while Tacitus found a follower only in Ammianus Marcellinus (330–400). Their influence extended to the Christian writers, as appears from the biography of Ambrosius by his secretary Paulinus, and even to the Middle Ages, when Einhardus took the same pattern for his "Life of Charles the Great." Eutropius, Aurelius Victor and Orosius drew on him freely and often transcribe his language so faithfully as to be of some little value in questions of textual criticism; and he was used as a source by Greek writers such as Cassius Dio, Lydus, and others.

His other biographies were not neglected: Apuleius made use of his book "On Famous Courtesans," Hieronymus wrote of the "Illustrious Men" of the Church in imitation of Suetonius' work of the same title, while the ecclesiastical chronographers, such as Julius Africanus, drew on his treatise "On the Kings."

His antiquarian and grammatical works were equally influential. Tertullian based his "De Spectaculis" on a similar work of Sue-

[32] See Macé, *l. c.*, p. 355; Schanz, "Geschichte der römischen Litteratur," Part 3, pp. 53 f.; etc.

[33] See page 208, above.

tonius, while Censorinus, Solinus, Macrobius, the commentator Servius, the scholiasts on Horace, Germanicus and Juvenal, the grammatical writers, and especially Isidore, the learned bishop of Seville, excerpted him freely and extensively. In this field, too, his influence extended to the Greek and Byzantine writers and inspired and furnished material for numerous works on natural history in the Middle Ages.

From its title and its general form the "Lives of the Cæsars" is naturally classed as biography, and it is also numbered among our historical sources. Strictly speaking, however, it is neither history nor biography. Great historical events are dismissed in a brief chapter, like Cæsar's Gallic campaigns, or with a casual allusion, as in the case of the defeat of Varus. Constitutional history receives relatively greater attention, but this too is subordinated to the personality of the emperors, about whose qualities and characteristics the minutest and most intimate details are given. Chronology is neglected, except for the dates of birth and death.

But when we examine the "Lives" as biography, we find them lacking in some of its most essential features. As a matter of fact, biography as the "faithful portrait of a soul in its adventures through life"[34] has reached its full development in comparatively modern times, and even now there is not entire agreement as to its function. The writer in Larousse's "Dictionnaire Universelle," for example, says:[35] "la biographie ne s'occupe que de la vie humaine, et elle ne l'étudie que dans les actions exterieures des individuels." Yet I think that most of us would agree that a biography in the true sense of the word should be more than a mere catalogue and should show the development of character as the result of heredity, education and environment. Of this there is practically nothing in Suetonius. He rather furnishes us with the raw material for biographies and his "Lives" differ from the modern conception as widely as do annals from history.[36] It does not occur to him to make comparisons between the various individuals whom he portrays, or to draw the psychological deductions that cannot escape

[34] Encycl. Brit., *s. v.*, III., p. 952.

[35] *S. v.*, II., p. 257.

[36] See Sempronius Asellio in Gellius, V., 18, 5 ff.

the thoughtful reader. In the "Life of Caligula" he gives us an appreciative sketch of the noble father Germanicus, leaving the reader to note the contrast with his unworthy son. He does, it is true, express the opinion that the latter was sound neither in body nor mind, but he attributes to this, not his acts of madness and his change from benevolence to tyranny, but merely the existence in the same man of two opposite traits, contempt of the gods and extravagant fear of thunder and lightning.[37] He has noted this same fear in Augustus, who had good reason for it in a narrow escape from death, and in Tiberius; but he has no thought of regarding it as a family trait: still less as a form of degeneracy or the effect of a guilty conscience.[38]

It is unnecessary to multiply examples of this kind. His method is sufficiently illustrated by his own remarks.[39] It consists in general in giving an outline of the life of his subject, commonly preceded by a sketch of the history of his family, and followed by an enumeration of his deeds in war and in peace and an account of his private life and habits. His good and bad qualities are presented in separate lists, rarely with comment of any kind.[40]

The "Lives" differ no less from the original Greek conception of biography than from that of modern times. The former consisted in a description of the ideal *βίος*, the art of living, as a model for imitation,[41] and the type endured for many centuries. In this aspect biography approaches the domain of philosophy, and Wilamowitz finds its beginnings in Plato, although it did not become common until the Hellenistic period. Our greatest example is of course the "Parallel Lives" of Plutarch, who was a young man in the days of Nero and probably wrote his biographies under the Flavian emperors, although they were not published until a later time. Side by side with the philosophical biographies, however,

[37] Calig., 51, 1.

[38] Cf. Juvenal, XIII., 223 ff.

[39] Aug., 9, 61, 94; Tib., 61; Calig., 22; Nero, 19.

[40] See, however, Tib., 21; Vesp., 16, 3; Titus, 1; 10, 2, etc., and on the last-named cf. Leo, "Die griechisch-römische Biographie," pp. 9 ff.

[41] See Wilamowitz-Moellendorff in "Kultur der Gegenwart," I., 8, pp. 116 ff.

though of somewhat later origin, we have the so-called "grammatical" type of the Peripatetics, originally designed as introductions to works of literature and drawing their material in a great measure from those works themselves, but afterwards extended to men eminent in other fields.[42] These are of the same general character as those of Suetonius, and undoubtedly influenced the form of his "Lives of Illustrious Men" and of his "Cæsars."

In considering the indebtedness of works of Roman literature to Greek models we must make a distinction between form and contents. It is well known that the Romans had made beginnings in various lines of literary endeavor before their introduction to the masterpieces of the Greeks, which would have resulted in the development of a native literature quite different from that which we may properly call Græco-Roman. Although this development was checked, it is equally well known that from the outset the Roman writers showed originality in the use of their models, for example, in the "contamination" of Greek plays and in the early invention of the *fabula prætexta* and *fabula togata.* But the influence of the form of the Greek writings was powerful from the beginning, and as time went on, regular rules for the various classes of literary composition were formulated, from which a rhetorically trained writer seldom ventured to deviate. This, however, is not necessarily attended with a lack of originality in the subject matter and its treatment. Horace for instance in his "Odes" followed the general principles and metrical schemes of Alcæus and Sappho, as he freely admits,[43] but as Professor Gildersleeve has graphically expressed it:[44] "if Alkaios and the rest of the nine lyric poets were to rise from the dead, Horace would still be Horace." Similarly it does not detract in the least from the merits of the "Agricola" as a masterpiece of literature that its author followed the traditional rules for the compo-

[42] While it was maintained by Leo that these were composed on a generally uniform plan, the newly discovered "Life of Euripides" by Satyros shows a departure from the norm in being cast in the form of a dialogue, with one principal and two minor interlocutors.

[43] "Odes," III., 30, 10: Dicar . . . Princeps Aeolium carmen ad Italos Deduxisse modos.

[44] *Amer. Jour. of Phil.*, XXXIII., p. 360.

sition of encomiastic biography.[45] Therefore the fact that Suetonius took as his model the "grammatical" biographies of the Greeks does not mean that the Romans derived the idea of that branch of literature from across the seas. On the contrary, there are good reasons for supposing that biography was one of the numerous forms of writing in which a beginning had been made before the days of Livius Andronicus, and it seems altogether probable that considerable progress had been made before that time.

At first thought we should not be inclined to look to the Romans for a form of literature in which the personal element is so strong, at least in the earlier period of their history. It is a commonplace of criticism that at the beginning of their national life they were led by their situation to form a military and political organization in which the interests of the community were paramount and those of the individual distinctly subordinate. To this we may attribute the late and exotic impulse to many forms of creative literature and the prominence given to military science and to law. Heine's witty characterization of the people as "eine casuistische Soldateska" contains as much truth as any generalization epigrammatically expressed. The Greeks, on the contrary, exalted the individual, and their greatness in literature and the arts was in marked contrast to their failure to achieve political unity, and their consequent early relation to Rome of *Græcia capta*. That they were so late in developing a biographical literature is doubtless to be attributed to their original notion of the moral and didactic function of that class of writing and its subordination to other forms of philosophical teaching, and to the relatively restricted nature of the "grammatical" biography in its earlier stages.

In spite of the suppression of the individual in early Rome, there were certain customs which favored the production of biographies of a laudatory character, the purpose of which was in part moral precept, as with the Greeks, and in part the gratification of national and family pride. We are told that it was usual at banquets to sing the praises of illustrious men and their houses. Cicero twice alludes

[45] See Hendrickson, "The Proconsulate of Cn. Julius Agrippa," *Univ. of Chicago Decenn. Publ.*, VI., 29 ff.

to this custom,[46] each time giving Cato as his authority. Valerius tutem alacriorem redderent," while Varro,[48] referring to the same custom, says that the singers were *pueri modesti*. Horace also refers to such songs,[49] and Macaulay attempted to give an imitation of them in his "Lays of Ancient Rome." Granting him, as we may, a fair degree of success in reproducing their spirit, although their form was of course quite different, it is clear that such lays were not biography, although they contained material for such writings and two powerful impulses to their composition. The theory of Perizonius, which Macaulay followed, with regard to an early ballad literature is of course generally given up, but we have no ground for doubting the testimony of Cato and Varro as to the existence of the custom referred to.

The Romans possessed a closer model for biographical literature in the funeral eulogies which were spoken from the rostra by a son or some other near relative in honor of distinguished men and women, and in the eulogies of their ancestors by magistrates on their entrance to office.[50] The former custom must have been a very early one, for Livy tells us[51] that it was first extended to women after the capture of Rome by the Gauls, in gratitude for their contribution to the city's ransom, an indication of the antiquity of the custom, whatever be the truth of the statement itself. The epitaphs of the Scipios may be regarded as condensed summaries of such eulogies, stripped of their minor details. For example:

> Cornelius Lucius Scipio Barbatus,
> Gnaivod patre prognatus, fortis vir sapiensque,
> Quoius forma virtutei parisuma fuit,
> Consol, censor, aidilis, quei fuit apud vos.

[46] "Tusc. Disp.," IV., 2, 3: gravissimus auctor in Originibus dixit Cato morem apud maiores hunc epularum fuisse, ut deinceps qui accubarent canerent ad tibiam clarorum virorum laudes atque virtutes; "Brut.," 19, 75.

Maximus[47] adds that their purpose was "quo ad ea imitanda iuven-

[47] II., 1, 10.

[48] In Nonius, s. v. *assa* (*vox*).

[49] "Odes," IV., 15, 25 ff.

[50] For the former see Polybius, VI., 53–54, and for the latter, Suet. Tib., 32, 1.

[51] V., 50, 7.

Taurasia, Cisauna, Samnio cepit;
Subigit omne Loucanam opsidesque abdoucit.[52]

In the eulogies themselves fuller details were given, as we see from Cæsar's funeral oration on his aunt Julia, a part of which is quoted by Suetonius.[53] In this oration Cæsar undoubtedly had a political purpose, as Napoleon had in his "Histoire de Jules César," and on other similar occasions, the opportunity was taken to justify one's own conduct or that of an ancestor.

That this custom led to the composition of formal biographies or at least to the publication of the funeral addresses themselves is a priori probable, and we have a parallel in the development of oratory as a branch of literature. According to Tacitus[54] the custom of publishing accounts of the lives of distinguished men (clarorum virorum facta moresque posteris tradere) was an ancient one (antiquitus usitatum), and we have references to such works, including autobiography,[55] at a comparatively early date. The custom naturally was given a fresh impulse by the growth of individualism at Rome, beginning with the domination of men like Sulla in times which might well be referred to by Tacitus as ancient, and reaching a high point with the foundation of the Roman empire.[56] To this period belongs one of our few surviving specimens of ancient biography, twenty "Lives" from the "De Viris Illustribus" of Cornelius Nepos, published about 44 B.C., which are of quite a different type than those of Suetonius.[57]

It is unnecessary to mention in detail, or to refer to all the biographies and autobiographies of which we have mention in this epoch and that of the early Empire.[58] While our only other surviving example is the "Agricola" of Tacitus, the interest of the Romans in this form of literature is sufficiently obvious.

[52] C. I. L., I., 30.

[53] Julius, 6, 1.

[54] Agricola, 1.

[55] See West, "Roman Autobiography," De Vinne Press, 1901.

[56] The same personal element appears in the historical writing of the period; cf. Leo, *l. c.*, p. 319.

[57] See Leo, *l. c.*, pp. 193 ff.

[58] For numerous references, and on autobiography as an original creation of the Romans, see West, *l. c.*

Although it may fairly be maintained that biography was original with the Romans, and although in the nature of the case the "Lives" of Suetonius are independent so far as their subject matter is concerned, the latter naturally followed the established rhetorical rules for the composition of such works. Just as Horace adopted the verse forms of Alcaeus and Sappho, so Suetonius took as his pattern the biographies of the Greek "grammatical" type,[59] since his purpose was not eulogy, but an impartial account, according to his own views of impartiality. Such merits, however, as his work possesses, and such defects as it labors under, are due to himself and not to any great extent to his models. That the books, interesting and valuable as they are, do not take first rank as literature is because he did not have the pen of a Tacitus; that they are rated no higher as an historical source is due to his lack of critical judgment.

The style of Suetonius is that of the investigator and scholar, rather than the man of letters. His purpose is clear statement, rather than rhetorical adornment or dramatic effect. He had no leaning towards the style which Seneca had made popular in his earlier years,[60] or that of the archaizers who set the fashion during his later life.[61] His ideas of an appropriate style appear in what he says of that of Augustus,[62] much of which might be applied to his own writings. As might be expected of a scholar, his choice of words is accurate and forceful, while his sentences are as a rule terse and packed with meaning. Now and then he turns out phrases worthy of Tacitus, but these seem to be due to his subject matter, like his intensely dramatic passages,[63] rather than to any conscious departure from his usual unadorned, "businesslike," and somewhat monotonous style.

Suetonius had at his command a wealth of sources of information, the greater number of which are lost to us, including historical works, memoirs, public records and documents, and private corre-

[59] Leo, *l. c.*

[60] Cf. Calig., 53, 2: Senecam tum maxime placentem; Nero, 52.

[61] See Seneca, "Epist.," 114, 13.

[62] Aug., 86.

[63] For example, the death of Julius Cæsar (82) and of Domitian (17), and the last hours of Nero (49).

spondence, published and unpublished. His intimacy with Pliny gave him access to senatorial opinion, while his position under Hadrian opened to him the imperial archives, either directly or through his colleague *Ab studiis.*[64] Few men could have had such opportunities, and he seems to have been as diligent a collector of material as the elder Pliny.[65] While he made little use of the inscriptions which are so highly valued in our day,[66] this was due to the abundance of his literary material and to the plan of his work. He occasionally makes use of them and shows an appreciation of their value.[67]

In general his methods are rather those of the scholar and investigator than of the inquirer and observer. He is a diligent searcher of records, but rarely records hearsay evidence, gathered from his grandfather and other men of the earlier time, or the results of his own observation.[68] As he comes nearer to his own day, when the former material was more scanty and the opportunities for gathering information of the latter kind more abundant, his interest visibly wanes. In the rare cases when he gives us an insight into his method of handling his material, as in the discussion of the varying opinions about the birthplace of Caligula,[69] he seems to examine it with care and good judgment, whenever he considered it necessary to do so; but the plan of his work seldom called for such critical methods, and it is quite possible that he has given us notice of all the cases in which he employed them. What he mainly desired was entertaining anecdotes and personalities, and he drew them indiscriminately from every quarter, either not realizing, or trusting his reader to discern that impartial opinions about Augustus were not to be expected in the letters and speeches of Mark Antony, or that one historian was not as trustworthy as another.

The result is that none of the Cæsars cuts a very heroic figure

[64] See Macé, *l. c.*, p. 110 f.

[65] Pliny, "Epist.," III., 5, 17.

[66] See Dennison, "The Epigraphic Sources of Suetonius," *Amer. Jour. of Arch.*, sec. ser., II., pp. 20 ff.

[67] See Aug., 7; Tib., 5; Calig., 23; Claud., 41; and for a full discussion of the subject, Dennison, *l. c.*

[68] See the references in note 15.

[69] Calig., 8.

in his pages. The great Julius appears as an unscrupulous politician, who aimed at supreme power from his earliest years and regarded any means of attaining it as justifiable.[70] He was ready to join in any attempt at revolution which seemed to promise success.[71] In spite of his moderate use of his victory and his many plans for the welfare of the state, Suetonius apparently believes that he deserved the fate which overtook him.[72] For Augustus and Titus he has an evident admiration, yet his method does not allow him to pass over the former's cold-blooded cruelty[73] and calculating seduction,[74] and the latter's violence, debauchery and shameless avarice.[75] In fact, his conscientiousness leads him even to record charges which he himself rejects.[76] On the other hand, he scrupulously recounts the good deeds and qualities of Tiberius, Caligula, Nero, and Domitian, although it is evident enough that his general opinion of those emperors is far from favorable. Vespasian fares best, for he is charged only with penuriousness, and even this Suetonius is inclined to justify on the ground of necessity.[77] Perhaps the most dramatic career of the whole series is that of the hard-headed, humorous Sabine, roused to seek political preferment only by his mother's taunts,[78] and retaining his simple habits and good common sense even after becoming ruler of the state. He bitterly offended Nero by going to sleep or leaving the theater while the emperor was singing,[79] was pelted with turnips at Hadrumetum,[80] and daubed with mud by order of Caligula for neglecting his duty of keeping the streets clean,[81] a fitting punish-

[70] Julius, 30, 5.

[71] Julius, 3, 5, 8, 9, 11.

[72] Julius, 76, 1: prægravant tamen cetera facta dictaque eius, ut et abusus dominatione et iure cæsus existimetur.

[73] Aug., 13, 27.

[74] Aug., 69, 1.

[75] Titus 7: constabat in cognitionibus patris nundinari præmiarique solitum.

[76] Claudius, 1, 5.

[77] Vesp., 16, 3.

[78] Vesp., 2, 2.

[79] Vesp., 4, 4.

[80] Vesp., 4, 3; Suetonius's naive sentence is worthy of a full quotation: exim sortitus Africam integerrime nec sine magna dignatione administravit, nisi quod Hadrumeti seditione quadam rapa in eum iacta sunt.

[81] Vesp., 5, 3.

ment for the offense and one of the flashes of genius of the madman who called Livia a "Ulysses in petticoats"[82] and dubbed Seneca's style "sand without lime."[83] While Vespasian lurked in retirement, fearful of Nero's vengeance for a lack of appreciation of his histrionic talents, opportunity found him in the form of the war in Judæa, which called for an energetic and able leader, such as Vespasian had shown himself under Claudius in Britain, and at the same time one whose humble origin made it safe to trust him with a great army. On becoming emperor he acquired the prestige and sanctity which were lacking in a parvenue prince by performing miracles,[84] but how little his head was turned is shown by the last joke of the inveterate humorist, uttered on his death-bed, "Woe's me! methinks I'm turning into a god."[85] Finally we have the fine picture of the sturdy old man struggling to rise and meet death on his feet, as an emperor should,[86] and dying in the arms of his attendants.

Although Suetonius doubtless intended his method to be strictly impartial, and though it would have been more nearly so in the hands of a more critical writer, it does not in reality give us a fair estimate of the emperors. To realize this we have only to imagine the biography of some prominent man of our own day, made up of praise and censure drawn indiscriminately from the organs of his own party and those of the opposition, and presented with little or no comment. So far from accepting his statements at their face value, the critical reader will hardly regard the judgment recently expressed by Professor Botsford as too severe:[87] "in the case of an author like Suetonius the student of history may begin his examination by rejecting, at least provisionally, everything that could not have been known to the public at the time of its alleged happening or that is not vouched for by trustworthy documents. This process of sifting will leave a substratum of facts on which the investigator may

[82] Calig., 23, 2.
[83] Calig., 53, 2.
[84] Vesp., 7, 2.
[85] Vesp., 23, 4.
[86] Vesp., 24.
[87] *Amer. Jour. of Phil.*, XXXIV., p. 88.

proceed according to his judgment to build his historical edifice." It is one of the weaknesses of Ferrero's interesting and suggestive work, that he now accepts the testimony of Suetonius and now rejects it as mere gossip, according to its relation to his own theories.

One cannot but wonder somewhat at the freedom with which a member of the imperial household[88] ventured to speak of the emperors of the past. It must be remembered, however, that Hadrian had no family connection with the men of whom Suetonius writes, and that the failings and vices of his predecessors made the virtues of the reigning prince more conspicuous. But consistently with the general plan of the work, we find no trace of that contrast of the evil days of the past with the happy present which appears in the third chapter of the "Agricola." We have only the very moderate remark at the end of the "Life of Domitian," where after speaking of the dream from which that emperor inferred a happier condition of the state after his death, Suetonius says: "sicut sane breve evenit, abstinentia et moderatione insequentium principum."

Suetonius has been stigmatized as a scandal-monger and a man of prurient mind. The former charge seems not to be justified. He did, it is true, collect all the damning details which seemed to him interesting, but even in the case of emperors like Caligula and Nero he is equally conscientious in assembling all that can be said in their favor. The so-called scandal-mongery is, in fact, a feature of the development of realism in the writings of the imperial period[89] and of an interest in all the details of the private life of prominent men.

The second charge is based in part on the accounts of the sexual habits of the emperors, and in part on the fact that he wrote a work "On Famous Courtesans." The latter argument may be dismissed as unconvincing, since the work has not come down to us and we have no means of knowing how the subject was treated. The former no more convicts him of pruriency than the amusing stories and witticisms which he has diligently collected justify us in crediting him with a sense of humor, in spite of numerous indications to

[88] The "Cæsars" was published while Suetonius was Hadrian's secretary, apparently in 120.

[89] See H. T. Peck, "Julius and Augustus," introd., pp. v ff.

the contrary.[90] In reality these details are presented with the same judicial coldness which is characteristic of his work in general, and he cannot be called obscene in the sense in which we may apply that term to Martial and Juvenal, for example. His discussion of such matters is undeniably plain and frank, but it must be remembered that the ancient conception of *pudicitia* was very different from the modern one.[91] Moreover the feeling which to-day leaves certain of his chapters in the original Latin or expresses them in veiled language is of comparatively recent date. Holland, for instance, in 1606 found no embarrassment in translating Suetonius into the frankest English and dedicating his book "To the Right Honorable and Vertuous Ladie Harington."

While it is obvious that we must regard the "Lives of the Cæsars" more or less in the light of a work of fiction, it deserves to be read as our best and most characteristic specimen of Roman biography, albeit with an open mind and in a spirit of scholarly scepticism.

[90] This subject will be discussed at another time.

[91] See Julius, 49, 1.

THE CONTROL OF TYPHOID FEVER BY VACCINATION.

By MAZYCK P. RAVENEL, M.D.

(*Read April 18, 1913.*)

The discovery of the prevention of disease by the use of attenuated cultures of bacteria is due to Pasteur, who, in 1879, discovered that when a chicken was inoculated with a weakened culture of the chicken cholera bacillus it became sick but soon recovered and thereafter could resist injections with the virulent germ without injury. Following Pasteur's suggestion, those methods by which we protect against disease through the use of attenuated cultures are spoken of as "vaccination," and the materials "vaccines," in honor of Sir Edward Jenner, who discovered vaccination against small-pox. Pasteur's later success in immunizing animals against anthrax by similar methods led to experiments on laboratory animals looking toward immunization against typhoid fever.

In 1896, Doctor (now Sir) Almroth E. Wright inoculated two men with killed cultures of the typhoid germ. Pfeiffer and Kolle in the same year immunized two men and made a subsequent study of the changes produced in the blood. In 1897, Dr. Wright published the results of his inoculations made on eighteen men, which convinced him that the method was a practical one in the prevention of the disease. Dr. Wright soon after tried it in the British army in India, but the outbreak of the Boer War gave him his first opportunity to carry it out on a large scale. The results were hard to collect accurately and opinions differed greatly as to the ultimate success of the method. Dr. Wright, however, believed that the incidence of the disease was diminished about one half, and that the mortality was favorably influenced to even greater extent.

We now understand some of the reasons for the varying effect of the vaccine. At that time the cultures were heated to a temperature of 60° C. in order to destroy their vitality. It has since been

shown that this amount of heat injures or destroys to a great extent the power of the germs to produce a good response in the formation of those substances on which the body depends for its protection. At the present time the cultures are killed by heating to 53° C.

It was tried next on a large scale in the German Colonial army during the Hereros campaign of 1904–07. The reports of this expedition show that the percentage of typhoid fever among the uninoculated was almost 10 per cent., whereas among the vaccinated it was only a trifle over 5 per cent. Further than this, the figures show that 76.01 per cent. of the inoculated who contracted the disease had mild or moderately severe cases, with the fatal cases numbering 6.47 per cent., whereas only 61 per cent. of the uninoculated had light or moderately severe cases, while the mortality reached 12.80 per cent. It was further shown that among the vaccinated 60 per cent. of the fatal cases occurred in those who had received only one dose of vaccine, 33 per cent. in those who had received two doses, and only 8⅓ per cent. in men who had received the three inoculations (Russell).

The value of the method has been made the subject of study by a number of commissions appointed by various governments all of which have made favorable reports. After careful consideration, anti-typhoid vaccine was introduced in the United States army as a voluntary measure in 1909. The favorable results were so striking that in 1911 it was made compulsory for all officers and enlisted men under the age of forty-five years. The most striking example of its efficacy is afforded by a comparative study of two bodies of soldiers, approximately equal in numbers, living under similar conditions during the same period of the year, and in much the same climate, one stationed at Jacksonville, Fla., in 1898; the other at San Antonio, Tex., during the maneuvers of 1911. At Jacksonville there were 10,759 men, with 2,693 cases of illness known, or believed to be, typhoid fever, and 248 deaths. At San Antonio there were 12,801 soldiers with only one case of typhoid fever, which resulted in recovery. During the same time there occurred in the city of San Antonio forty-nine cases of typhoid fever with nineteen deaths, showing that the infection was prevalent in that community and demonstrating that the difference in the incidence of typhoid fever

was almost certainly due in large part to vaccination. As the troops had considerable freedom in visiting the city, this conclusion is rendered all the more certain.

Preparation of the Vaccine.

The method of preparation varies slightly in different laboratories, but the following is probably most often followed.

Pure cultures of the typhoid bacillus are grown on slanted agar, preferably in flat bottles, which give a large surface for culture. At the end of forty-eight hours the bacilli are scraped off and suspended in normal salt solution. The suspension is then heated for one hour to a temperature of 53° C., preferably in a water bath, after which it is standardized by comparing it with normal blood. Equal parts of normal human blood and the suspension of bacteria are mixed, and oftentimes diluted in order to facilitate counting. Spreads from the mixture are made on slides, stained, and a large number of fields (usually one hundred) examined, and both red blood cells and bacteria are counted. The average number of blood cells per field and the average number of bacteria per field are then compared. The normal blood count is taken at five million red cells for each cubic millimeter. Knowing this, it is easy to determine the number of germs per cubic centimeter. The vaccine is then diluted with normal salt solution until the mixture contains one thousand million bacilli per cubic centimeter. If it is to be sent out to physicians in general practice, it is better also to make a further dilution of the suspension to five hundred million per cubic centimeter for the first injection so that the size of the dose may be kept uniform while the number of bacteria contained in the dose is varied. The vaccine may be preserved for considerable lengths of time by the addition of one fourth per cent. of lysol, or carbolic acid. When kept in a cool and dark place its properties are maintained uninjured for at least three months.

It is also advised that the material should not be used until it is three weeks old, as freshly prepared vaccine apparently is more apt to give severe local reactions than that which is older.

Polyvalent Vaccine.

At the present time many laboratories are using what is called polyvalent vaccine; that is, one made of a number of pure cultures derived from different sources, mixed together in approximately equal proportions. Thus, in preparing vaccine for the immunization of the French soldiers in Morocco cultures were obtained from cases of typhoid fever occurring in that country. Some bacteriologists also add to the vaccine cultures of the para-typhoids, A and B. At the Laboratory of Hygiene of the University of Wisconsin it is our invariable practice to prepare polyvalent vaccine.

Vincent, who has prepared most of the vaccine used in the French army, uses twelve different strains. After full growth has been obtained, the bacteria are autolized in salt solution with frequent shaking, and killed by being subjected to the action of sulphuric ether.

Dosage.

In America the dose universally employed is that advised by the army. Three doses are given ten days apart. The first dose consists of five hundred million bacteria, the second and third one thousand million each. The injections are made preferably in the upper arm about the insertion of the deltoid muscle, and are given under the skin and not into the muscles. The skin is sterilized with iodine, and the sterile needle is thrust through the area thus prepared. It is customary to vaccinate about four o'clock in the afternoon so that any reaction which takes place will occur during the night and be practically over with by the next day.

The use of alcohol in any form is prohibited, as even moderate amounts seem to increase the severity of both local and general symptoms.

No special precautions are necessary and the vaccine does not usually interfere with the ordinary vocations of life. Occasionally slight chilliness and even rigors may occur combined with headache, general malaise, and sometimes distinct nausea. Locally, there is an area of redness and tenderness, the worst of which is over with within twenty-four hours. Suppuration never occurs.

The vaccine is well borne by women and children, but the dose

for children should be smaller than that given to adults in proportion to their weight, the dose given being that proportion of the adult dose which the weight of the child bears to the average adult weight, namely, one hundrd and fifty pounds.

Major Russell reports that of three hundred and fifty-nine children vaccinated in no case had any bad effects been observed, and no case of typhoid fever had occurred amongst them up to the time of his report. In approximately one hundred and twenty-nine thousands injections in adults there were only six tenths of one per cent. of severe reactions. Of these, three tenths of one per cent. followed the first injection.

The vaccine should not be given to anyone running a temperature. Vincent has shown that in persons suffering from malaria the occurrence of a paroxysm is oftentimes precipitated by the giving of a dose of vaccine. In the enormous practice in the United States army the only serious result which has been observed occurred in a man suffering from an unrecognized incipient tuberculosis. The rule, therefore, is to be sure that the person about to be inoculated has a normal temperature.

General Application of the Method.

It is evident that the use of vaccine is particularly applicable to armies or other large gatherings of men who are apt to be in temporary quarters deprived of the usual sanitary arrangements for the disposal of sewage. However, the use of the vaccine has a very much wider range than this, being of great value in the suppression of local epidemics. A typical case of its use under these circumstances will be mentioned.

A water borne epidemic occurred in Avignon, France, a town with a population of 49,000, in 1912. Six hundred and forty-four cases with sixty-four deaths were reported, but it is certain that the total number of cases reached 1,500. The garrison of the town consisted of 2,053 men. Of these, 1,366 were vaccinated; 687 not vaccinated. Among the unvaccinated there occurred 159 cases of typhoid fever with 21 deaths; while not a single case occurred amongst those who had been vaccinated. All lived under the same

conditions, drank the same water, ate the same food, and did the same work.

In the State of Wsiconsin, the bacteriologist of the State Laboratory of Hygiene has administered the vaccine in two outbreaks, one occurring in a county hospital, and the other in a small village. At the institution one hundred and six persons were vaccinated. One case of typhoid fever occurred amongst those who received the vaccine, but within such a short time that it was evident that the person had been infected before vaccination was practiced. The case was atypical and of the mildest type, resulting in recovery, showing that the vaccine exercises a favorable effect when given during the period of incubation. During an epidemic in the town of Warrens, Wis., one hundred and sixteen persons were vaccinated. The epidemic ceased at once, and since that time only one case of typhoid fever has been reported among the vaccinated.

The method is of the greatest use in institutions, especially hospitals. It has long been known that nurses were more liable to typhoid fever than other people, as the result of direct exposure.

Dr. Spooner began the inoculation of nurses in the Massachusetts General Hospital, and reported that for the first time in the history of the institution no nurses had suffered from typhoid fever during the year. The practice has, since October, 1912, been extended by him to twenty-three hospitals in Massachusetts. In all, 1,361 individuals have been treated. In the same hospitals there have been six hundred and seventy-four persons exposed but not vaccinated. Among the vaccinated there have been three cases of typhoid and para-typhoid fever. Among the uninoculated there have been seventeen cases of typhoid and para-typhoid fever. It is evident that a large amount of protection was furnished by the inoculation among those especially exposed to the disease.

In the State of Wisconsin we advise that whenever a case of typhoid fever occurs in a family the other members of the family shall receive the protective inoculations. It is impossible to give exact figures of the results, but several very striking instances have been reported to us.

In Watertown vaccination was advised for the husband of a woman suffering from typhoid, and two trained nurses who were in attendance. One of the nurses refused to be vaccinated, saying that she was immune. About three weeks after leaving the case she went down with a severe case of typhoid fever, and was ill for several weeks. The husband and other nurse remained well.

The vaccination has been carried out also to a large extent in the National Guard of Wisconsin. This is still on a voluntary basis. In 1912 a large number of troops submitted to the inoculations, but many refused them. Some of those who declined were taken sick with typhoid fever soon after reaching home. We have not been able to trace any case among those who received the full vaccination.

Another condition in which the use of anti-typhoid vaccine is likely to prove of great service is in the treatment of typhoid bacillus carriers. During the last few years many cases have come to light in which individuals have been carrying the typhoid fever germ, and have been discharging it from their bodies for longer or shorter periods of time; such persons are known as "carriers." The most noted of these cases, "Typhoid Mary" in New York, is well known to the general public. Another striking example came to light on the steamship *Acme* sailing from San Francisco. So many cases of typhoid fever occurred among the sailors on this vessel that she obtained a bad name as the "fever ship," and it was difficult to secure good crews. The treatment of such cases has been a puzzle to the medical profession, and it seemed impossible to keep these persons in hospitals or under quarantine indefinitely. It has been found, however, in a number of cases such as those reported by Brem, and by Currie and McKeon, that the bacilli rapidly disappeared from the discharges of the body after administration of a vaccine made from the particular strain of typhoid germs recovered from the patient—what is known as an autogenous vaccine.

There are nineteen cases of carriers recorded in literature that have been treated with typhoid vaccine. Fourteen of these were successful; five were failures, though two of the latter were helped for a time.

In conclusion, I think we are justified in saying that in anti-typhoid vaccination we have an efficient method for the control of the disease under many and varying circumstances. It can never, however, take the place of sanitation, the proper disposal of sewage, and provision of safe water supplies.

Wisconsin State Laboratory of Hygiene,
Madison, Wis., April, 1913.

THE TREATY OBLIGATIONS OF THE UNITED STATES RELATING TO THE PANAMA CANAL.

By CHARLEMAGNE TOWER.

(*Read April 17, 1913.*)

I beg leave to call to the attention of the society a subject which has been considerably discussed of late, in Congress and throughout the country, and cannot be considered in any sense to be new; but, in spite of this fact, and of a certain familiarity which it has acquired in men's minds from frequent mention, I am inclined to the thought that it can scarcely be too plainly or too forcibly brought before the sober consideration of the American people,—the international obligations undertaken by the United States in the treaties relating to the Panama Canal.

The subject of a canal across the narrow strip of land that joins the two continents is one, indeed, that is nearly contemporaneous with the discovery of America; for its advantages made themselves evident even to the earliest explorers and navigators, who, upon returning to Spain, in 1528—more than 150 years before William Penn entered the Delaware,—presented to the Emperor Charles V. a plan for the opening of a waterway through the Isthmus of Panama; a project that never was lost sight of and which acquired greater importance to us, both from our political and commercial point of view, after our separation from Great Britain and the establishment of our independent nationality.

In 1826, Mr. Clay, then Secretary of State, wrote, in connection with a Congress at Panama:

> "A cut or canal for purposes of navigation somewhere through the isthmus that connects the two Americas, to unite the Pacific and Atlantic Oceans, will form a proper subject of consideration. That vast object, if it should be ever accomplished, will be interesting, in a greater or less degree, to all parts of the world."

We were not in a position at that time to think of undertaking such a work ourselves, though our government was alive to the opportunity and wished to participate in the advantages that would arise from a canal; and Mr. Clay added:

> "If the work should ever be executed so as to admit of the passage of sea-vessels from ocean to ocean, the benefit of it ought not to be exclusively appropriated to any one nation, but should be extended to all parts of the globe upon the payment of a just compensation or reasonable tolls."

The progress of events and the growth of our importance as a nation enlarged the interest of the people of the United States in the passage through the isthmus, which was taken up in the House of Representatives in compliance with a memorial from the merchants of New York and Philadelphia in 1839. A resolution was adopted by the House that the President should be requested:

> "To consider the expediency of opening or continuing negotiations with the governments of other nations, and particularly with those the territorial jurisdiction of which comprehends the Isthmus of Panama, for the purpose of ascertaining the practicability of affecting a communication between the Atlantic and Pacific Oceans, by the construction of a ship canal across the isthmus, and of securing forever the free and equal right of navigating such Canal to all nations."

A treaty was entered into, seven years later, in 1846, between the United States and the Republic of New Granada, which was the first effective step taken by our government in the direction of the actual transit across the isthmus and of our participation in its construction and maintenance of way. This was a treaty of peace, amity, navigation and commerce with New Granada, and was continued in operation by the Republic of Columbia into which that state was subsequently transformed, and it is to this agreement, entered into by us during the administration of President Polk, through an immense amount of negotiation and correspondence that has taken place since between ourselves and other governments, particularly those of the Central and South American republics as well as Great Britain and France, that may be traced the origin of the interests and claims under which the United States have constructed the canal and are in control of the territory of the canal zone on the isthmus to-day. The treaty extended to the citizens of the

United States all the privileges and immunities of commerce and navigation in the ports of New Granada that are enjoyed by the Granadian citizens themselves, and the government of New Granada guaranteed to the United States, "that the right of way or transit across the Isthmus of Panama upon any modes of communication that now exist or that may be hereafter constructed, shall be open and free to the Government and citizens of the United States." In return for these favors the United States guaranteed: "positively and efficaciously, to New Granada, the perfect neutrality of the isthmus, with the view that the free transit from the one to the other sea may not be interrupted in any future time while this treaty exists"; and, in consequence, the United States guaranteed, "in the same manner, the rights of sovereignty and property which New Granada has and possesses over the said territory."

Therefore we had acquired a controlling influence at Panama which enabled us to play so prominent a part that we might begin to make effective plans for the construction of a canal; whether we should decide to build it ourselves, or whether the work should be done by others, it was quite certain that no canal could be made without our consent. We had secured the constant enjoyment to ourselves of the commercial privileges enjoyed by the inhabitants of New Granada, and as New Granada was a weak power we made the stipulation in return for the favors that she had shown to us that the United States government with its superior strength would protect New Granada in her rights of ownership on the Isthmus of Panama and would guarantee that she should always maintain her sovereignty over that territory. We failed afterwards to carry out our agreement in this respect; and the protest of Colombia, taken upon its merits as a matter of international law, is very serious,—but that belongs to another subject.

Our attitude was made plain at that time by the message with which the President submitted this treaty to the Senate, in 1847, for its approval and ratification, in which he announced formally the policy of the United States to develop the communication through the isthmus for the benefit of the commerce of the world at large.

Mr. Polk declared that the treaty did not "constitute an alliance

for any political object, but for a purely commercial purpose, in which all the navigating nations of the world have a common interest."

"The ultimate object is to secure to all nations the free and equal right of passage over the isthmus. If the United States should first become a party to this guaranty, it cannot be doubted that similar guarantees will be given to New Granada by Great Britain and France."

If the proposition should be rejected by the Senate, the President said, "we may deprive the United States of the just influence which its acceptance might secure to them, and confer the glory and benefits of being the first among the nations in concluding such an arrangement upon the government either of Great Britain or France."

But, at the time that this treaty was made, Great Britain claimed dominion in certain parts of Central America over which she exerted authority and of which she was in actual possession; these were the territory extending along the coast of Guatemala, called Belize or British Honduras, including an island called Ruatan and other Bay Islands, and she asserted a protectorate over a long stretch of Nicaraugua inhabited by the Mosquito Indians, called the Mosquito Coast. She had a more direct claim upon and closer personal relation with the people of Central America than we had,—her occupation of British Honduras dating back at least to a treaty which she made with Spain in 1786.

In pursuance of our policy, however, of creating a neutral territory at the isthmus, and of preventing the establishment there by any single foreign nation of exclusive control, we proposed, in 1850, that Great Britain should unite her interests with ours in order that not only the canal should be built upon fair and equitable terms, "but that its construction should inure to the benefit of all nations and should offer equal opportunity to the commerce of the world; and for this purpose we invited Great Britain, and she consented, to enter into a convention with us with the intention of setting forth and fixing the views and intentions of both governments, with reference to any means of communication by ship canal which may be constructed between the Atlantic and Pacific Oceans by way of the river San Juan de Nicaragua, to any port or place on the Pacific

Ocean." This was the Clayton-Bulwer Treaty, which was signed at Washington on the nineteenth of April, 1850, by Mr. John M. Clayton, then Secretary of State, and Sir Henry Lytton Bulwer, British Minister to the United States. By it:

"The Governments of the United States and Great Britain declare that neither the one nor the other will ever obtain or maintain for itself any exclusive control over the ship Canal, will not fortify, or colonize, or exercise any dominion over Nicaragua, Costa Rica, the Mosquito Coast, or any part of Central America; also, that neither Great Britain nor the United States will take advantage of any intimacy or alliance that it may have with any government through whose territory the Canal shall pass, for the purpose of acquiring or holding any rights or advantages in regard to commerce or navigation through the Canal which shall not be offered on the same terms to the Citizens or subjects of the other."

The treaty having thus provided for the joint action of Great Britain and the United States, and having agreed that the two governments should give their support and encouragement to any persons or company who might first offer to begin the canal with the necessary concessions and capital, the two contracting nations included in it the following statement:

"The Governments of the United States and Great Britain having not only desired, in entering into this Convention, to accomplish a particular object, but also to establish a general principle, they hereby agree to extend their protection, by treaty stipulations, to any other practicable communications, whether by canal or railway, across the isthmus which connects North and South America, and especially to the interoceanic communications, should the same prove to be practicable, which are now proposed to be established by the way of Tehuantepec or Panama";—it being understood—"that the parties constructing or owning the same shall impose no other charges or conditions of traffic thereupon than the aforesaid Governments shall approve of,—and that the same canals or railways, being open to the citizens and subjects of the United States and Great Britain on equal terms, shall also be open on like terms to the citizens and subjects of every other State which is willing to grant thereto such protection as the United States and Great Britain engage to afford."

Thus, the Clayton-Bulwer treaty became the foundation for the understanding between the United States and Great Britain and provided for an absolute equality between them in regard, not only to the protection which they united to give to any interoceanic communication that should be established, but also formally declared that

both governments should approve of any charges or conditions of traffic,—that is to say, tolls,—which might be imposed, and that no such tolls should be imposed, in fact, which had not the approval and consent of both governments.

The United States government considered that it had entered into an agreement that was both just and equitable toward both parties, as a definition of the rights and duties of each and a basis upon which the isthmian canal should be built as a benefit to the commerce of the world.

And further, we not only held ourselves to be bound by the stipulations of this agreement, but we called upon Great Britain to sustain her part of it by a very strict interpretation of the law, quite beyond what the British Cabinet had expected in entering into the engagement, and a good deal more than it was willing at first to concede; for we contended that by the provisions of the treaty both nations had promised not: "to make use of any protection or alliance which either has or may have with any state or people for the purpose of fortifying or colonizing Nicaragua, Costa Rica, the Mosquito Coast, or any part of Central America, *or of assuming or exercising dominion over the same.*" And we called upon the British government, under this provision, not only not to extend its political influence in Central America but also to give up such claims as it might already have acquired in British Honduras, the Mosquito Coast and the islands of the sea.

This was not at all what Great Britain had understood to be her position under the treaty, and Lord Clarendon declared, (1854) that the contracting parties did not intend to include within its action "either the British settlement in Honduras nor the islands known as its dependencies," that whatever claims or influence Great Britain may have had there previously should remain undisturbed,—that the only question which might arise in regard to this was one relating to the boundary line of Honduras,—as to what was British Honduras and what was not.

"To this settlement and these islands the treaty we negotiated was not intended by either of us to apply,—and the British government is more warranted in this conclusion from the fact that the United States sent a

Consul to the settlement, in 1847, which Consul had received his exequatur from the British government which was a recognition of the British claim.

"But, on our side," Mr. Marcy, Secretary of State, declared in answer to this, (1856), "Great Britain had not any rightful possessions in Central America, and at the same time, if she had any, she was bound by the express tenor and true constrüction of the Clayton-Bulwer Treaty to avacuate them, so as to stand on precisely the same footing in that respect as the United States."

This defines our position in regard to the affairs of the isthmus; it insists that Great Britain shall place herself upon an exact equality with us; that she must give up any claims or privileges in which we did not share, in order that we may be precisely alike; but it marks also our obligation toward Great Britain,—for whilst we insisted that she should be on an equal footing with us, we promised that we should be upon an equal footing with her. We won our case and England, giving up the Mosquito Coast and the islands, came ultimately to our understanding, because of the Clayton-Bulwer Treaty;—but the provision of the treaty was that: neither the United States nor Great Britain should exert any influence that either may possess, "for the purpose of acquiring directly or indirectly, for the citizens of the one any rights or advantages in regard to Commerce or navigation through the said Canal which shall not be offered on the same terms to the citizens or subjects of the other."

General Cass said, (1858):

> "What the United States want in Central America, next to the happiness of its people, is the security and neutrality of the inter-oceanic routes which lead through it. If the principles and policy of the Clayton-Bulwer Treaty are carried into effect, this object is accomplished."

It is to be observed that there are two distinct points of agreement which are set forth in this Treaty as well as in all of the voluminous correspondence that had taken place in regard to it,—which points of agreement have never been lost sight of as the basis of the negotiations relating to the Canal across the isthmus; namely the neutrality of the canal itself and the absolute equality between the United States and Great Britain in connection with it. We demanded it from the start and Great Britain has acceeded to

our demand with that principle in view, which has never been changed.

She was willing to join with us in building the canal, or she was willing that we should build it alone. And when after a good many years of delay we announced to her that we were in a position to undertake the work, and we made suggestions to her looking to that result, she agreed to make a new treaty with us, to supersede the old one, in order that the intended benefits might be secured and the work should progress.

The new treaty was signed in November, 1901, by Mr. John Hay, Secretary of State, and Lord Pauncefote, the British Ambassador, whence it has since become widely known as the "Hay-Pauncefote Treaty."

By this contract the two powers

"Being desirous to facilitate the construction of a ship-canal to connect the Atlantic and Pacific Oceans, by whatever route may be considered expedient, and to that end to remove any objection which may arise out of the Convention of the nineteenth April, 1850, commonly called the Clayton-Bulwer Treaty, to the construction of such canal under the auspices of the Government of the United States, without impairing the 'general principle' of neutralization established in Article VIII. of that Convention, agreed that: The present Treaty shall supersede that of April 19, 1850. That the canal may be constructed under the auspices of the Government of the United States,—and that, subject to the provisions of the present Treaty, the United States shall enjoy all the rights incident to its construction, as well as the exclusive right of providing for the regulation and management of the canal. And, in order to make plain the understanding between ourselves and the British Government with whom we were dealing, we made this specific stipulation: (Article III.).

"The United States adopts, as the basis of the neutralization of such ship-canal, the Rules, substantially as embodied in the Convention of Constantinople (28 October, 1888), for the free navigation of the Suez Canal, that is to say:

"1. The Canal shall be free and open to the vessels of commerce and of war of all nations observing these Rules, on terms of entire equality, so that there shall be no discrimination against any such nation, or its citizens or subjects, in respect of the conditions or charges of traffic, or otherwise."

This is not an obscure subject. It is a treaty into which the United States entered openly and freely with Great Britain,—a treaty based upon all that had gone before, both in our correspondence and

our engagements under which Great Britain placed herself and her interests upon an equality with us and with our interests in Central America. The situation is one that we have created for ourselves.

It is not a question as to whether we made a good bargain or a bad one, but it is a matter of the greatest importance to the American people that the Government of this country shall fulfill its engagements and carry out always and in every particular its international obligations.

PHILADELPHIA,
April 17, 1913.

A COUNSEL OF PERFECTION: A PLAN FOR AN AUTOMATIC COLLECTION AND DISTRIBUTION OF A STATE TAX FOR HIGHER EDUCATION.

By J. G. ROSENGARTEN.

(*Read April 17, 1913.*)

The example of the western state universities suggests a similar organization for other states. Here in Pennsylvania the University, dating from 1740, when under the inspiration of Whitefield, the plan of a school was first mooted, has outgrown its modest endowments. Biennially it goes to the legislature to ask help to carry on its work. In the interval it appeals to its alumni and friends for help to meet its pressing needs, higher salaries, a larger teaching force, and more buildings and appliances for its multifarious educational needs.

What is true of the University of Pennsylvania is true of all other universities and colleges of Pennsylvania, and of the East and South, and no matter how large their endowments and income, each and all require more money to keep pace with the growing expenses of higher education in the modern university.

It needs no apology to broach the matter here, for Franklin founded both the American Philosophical Society and the University of Pennsylvania. In fact after the Revolution the charter of his College of Philadelphia was taken away, and a Charter given to the University of the State of Pennsylvania, and the constitution affirmed the duty of the state to help it. Later the charter of the college was restored, and still later the college and the university were united in the University of Pennsylvania, and it has grown to its present great estate under that charter and that name.

From time to time the state has aided it, and private munificence has enabled it to provide the splendid buildings in which it is now housed, with College and Law and Medical Departments, and to

maintain the Towne Engineering School, and the Wharton School of Finance and Economy, and the Zoölogical and Dental and Veterinary Schools, and a long list of endowed Professorships and Fellowships and Scholarships and prizes. With all these, and the other resources of the university, there is still an annual deficit which must be met. To do so would require an additional endowment sufficient to provide an income of half a million dollars to meet the needs of the university. How to provide this is a question that taxes the university authorities and exacts time, thought and anxiety of provost, trustees, faculty and alumni, when they ought to be free to give attention to the work of instruction and to raising the standard of education in all its departments.

Illinois, Indiana, Iowa, Montana, Wisconsin, are among the western states which have state universities. In their state constitutions provision is made for an automatic assignment of a small part of the state taxes for their support. Thus all appeal to the state legislature for support is made unnecessary. In Wisconsin, and in many other universities, colleges, etc., the United States Land Grant is made part of the endowment of the state university, and for agricultural and technical schools. Iowa has recently put all its educational institutions under a single governing board. All the western universities have out of the increasing wealth and revenues of their states provided incomes growing in proportion to their needs, and their activities keep pace with them. University extension lectures carry their teachers to every part of their state, and every branch of education is fostered under intelligent guidance, with university men spreading the influence for higher and better education.

A constitutional convention is soon to be called in Pennsylvania. There a plan should be formulated, submitted and discussed for a reorganization that may strengthen institutions of higher education in Pennsylvania. The plan and method of securing automatically a portion of the state revenue for the purpose of education are now in force in twenty one states, so that there is little novelty in the idea, for it has been in practical operation in all of them, with various differences, and yet almost uniformly successful results. Only recently, in acknowledging a paper on German Universities, that

Nestor of both American and German universities, the Hon. Andrew D. White, of Cornell, wrote:

"It is doing a duty to the country to call attention to the evils caused by the scattering of resources among so large a number of institutions bearing the name of 'University.'

"The worst affliction of our whole existing system is the fact that such a multitude of institutions which ought to be called 'Colleges' are pretending to do University work, while they are in no condition to do the duties worthy of that name.

"What the country needs is a concentration upon a smaller number of Universities, with a large number,—no matter how large indeed,—discharging a function akin to that of the 'Gymnasia' in Germany, which might very honorably be called 'Colleges.' An example of a better practice may be found in some parts of New England, where institutions, some of which were up to a recent time called 'Universities,' have become frankly 'Colleges.'

"We are about to have Universities which will give us high rank throughout the World, and among them especially the State Universities of the West, as well as some that have been established upon large foundations in the eastern part of our country.

"As to the Western State Universities, their progress is simply amazing. There has been developed an honorable pride in them by their respective states, and this has been deepened by a very honorable rivalry between sundry commonwealths, as for example Michigan, Wisconsin, and Minnesota, which has resulted in a magnificent fruitage.

"While the standard of scholarship is kept deplorably low in some of the smaller Universities, it has been steadily rising in many of the better endowed institutions. The increase of lectures by distinguished foreign professors at various American Universities of the better sort, will be productive of great good. Cornell, for example, is about to have an extended course of lectures on American History, by a renowned Oxford Professor upon the Goldwin Smith Foundation. Who would not gladly exchange our scattered flock of Universities and Colleges, running up into the hundreds, for the twenty two Universities of Germany?"

There too the important cities of Hamburg and Frankfurt are about to coördinate all their existing institutions of science, art and literature, into great metropolitan universities, retaining all the useful elements of successful and thorough education and training, and elevating the standard of work.

Against the twenty-four universities, and nine technical schools, of Germany, the last report of the Commissioner of Education of the United States reported nearly five hundred universities and

colleges for men, and one hundred and thirty for women, and over one hundred and fifty technical schools, nearly one hundred law schools, and proportionately numerous medical, dental, pharmaceutical, and other allied special schools. With this enormous disparity in numbers, it is easy to see why the German schools and universities do their work thoroughly and well.

The state regulations and examinations for the bar and for medicine and various other professions and employments, show the need felt for something more than the diploma of university, college or technical school.

A state university, representing, in its government, all the institutions of instruction in education, in all its varieties, general and technical, would give strength to each and all of the schools affiliated with it, and its degrees, awarded on their recommendation, would be greatly enhanced in value.

The first step in Pennsylvania would be to take advantage of the proposed constitutional convention, and introduce into the new state constitution,

First.—Provisions for an automatic appropriation of part of the revenue of the state, to higher education, to be distributed in the maintenance of a University of the State of Pennsylvania, and allied colleges and technical schools, thus going back to the wise provision of the Constitution of 1779.

Second.—Legislative power to strengthen and increase the power of the College and University Council, with the Governor, the Superintendent of Public Instruction, the Attorney General, State Officers, ex officio, and the presidents of the University of Pennsylvania, Pittsburgh, Lehigh, Bucknell, and of Washington, Jefferson, State, Franklin & Marshall and other colleges and other institutions, the members.

Third.—To give that board power to distribute the state educational fund among the state universities, colleges, technical schools and other institutions of learning, science and art, on such terms as to numbers of teachers and students, standards, and other conditions as may be prescribed by the college and university council.

Fourth.—To make all universities, colleges, technical schools and

institutions for higher education, branches of the university of the state, retaining their names, organization, endowments, etc., but requiring annual returns of all the details of numbers, income, work, etc., on a uniform basis, with provision for inspection, audit, examination, so thorough that the highest standard of efficiency may be secured and maintained, under the penalty of losing any claim to the income from the state education fund; the council to have the right and privilege of approving and recommending the degrees in course conferred by the university and other universities and colleges of the state, with power to revoke or modify charters of any affiliated institution for cause.

Fifth.—The college and university council to have power to consolidate existing institutions working in one district or multiplying the work that could be better done by one strong institution, thus giving to the state one or more medical, legal, technical or other schools, in lieu of an unnecessarily large number of small schools, weakened by competition, lessening standards, and not really serving the state, owing to insufficient means and inefficient methods.

Sixth.—Uniting with the state university, libraries, university extension work, scientific and art and technical schools and museums, in such a way that all unnecessary duplication may be prevented, and higher education ensured through uniform grants from the state educational fund.

Seventh.—The college and university council to have the inspection of the normal schools, in such a way as to unite in close sequence the methods of education, from the public and private schools, the normal schools, etc., through the colleges and technical schools and up to the university.

Twenty states have made provision in their constitutions for automatic collection and distribution of a small part of the revenue of the State to aid in the work of education of its people, and Pennsylvania should make similar provision in its new constitution. It would increase the efficiency of its institutions of learning, relieve the legislature of a task which is no part of its proper duty, free the trustees and officers and faculties of our universities and colleges from the necessity of going to the legislature and the governor of

the commonwealth, give them a right to a part of the state revenue thus set apart for education, elevate the standards and enhance their efficiency, by allying them with the University of the State of Pennsylvania, and give their degrees a position recognized through the state and beyond it.

This may be a counsel of perfection, but none the less well worth discussion and careful consideration by the American Philosophical Society, true to its purpose of promoting useful knowledge. What can be more useful than to know how best to bring to bear on education the means and methods of securing that which is best fitted to prepare men and women to be good citizens, to teach them all that is necessary, to secure them the best schools for every profession and occupation, and to reform existing institutions of learning, so that they may do the greatest good to the largest number?

Make the state supply from its plethoric treasury, the money required for higher education, as it does for secondary and elementary schools, and then the distribution may be safely put into the hands of the state's college and university council, composed of state officers and the representatives of the universities and colleges and technical schools. Among them will be found men who will see that the state's money is well spent, with a proper distribution between buildings and maintenance, salaries and expenses incidental to instruction.

The state will supply through its *ex-officio* members and its trained inspectors due protection against undue expenditure of any kind.

The state college and university council may properly insist that wherever money is given for any special purpose, it shall be enough to provide for future maintenance, and not be, as it too often is the case today, a burden on income. There are plenty of reforms incidental to a reorganization of our institutions of learning, that will need the careful consideration of the state college and university council. A few years will serve to show how unnecessary duplication of work can be prevented, how neighboring colleges can be united into one strong college, how technical and professional schools can be strengthened by reducing their number, and increasing their

efficiency, how an exchange of professors may be systematized to the advantage of teachers and students, and how the standard of education may be raised.

Much will be done by the teachers themselves, and there can be no better inspiration to improve methods than to draw from the great body of men trained in the work of education, the results of their experience. Of course there will be impracticable suggestions and unworkable plans proposed, but those will all be submitted to the trained and experienced members of the State college and university council, and after full discussion, their judgment will choose the good and reject the bad. Plans and methods of teaching will be entrusted to experienced teachers, and the profession will rise in dignity and importance, as the work shows the good results of their experience, knowledge and ability. All this and much else can be accomplished if the new constitution of Pennsylvania makes the business of education a matter of state support and state government.

Andrew D. White, that Nestor of Higher Education in this country, first president of Cornell University, and always its inspiration, read a paper on "Advanced Education," before the National Education Association at Detroit, in 1874. Urgent arguments are brought forward for a reorganization of American universities and colleges and technical schools as part of the work of the state. Dr. White urges the necessity of careful public provision by the people for their own system of advanced instruction as the only republican and democratic method. Public provision, he said, is alone worthy of our dignity as citizens. It will stimulate private gifts and free them from the dogmas of living donors and dead testators. The nucleus of Cornell University was the national land grant, which has been supplemented by an increasing flow of private gifts to the endowment.

The state of Michigan made the national land grant the foundation of its great university, and has added to it from time to time with the best results. It has thus strengthened the whole system of public education throughout the state. The national grant and the state grant together have thus been united to make a great university, and provide the endowment of advanced instruction, and to coördi-

nate education from the primary school to the highest technical and scientific and classical and collegiate and professional training.

Such an example and that of twenty other States all point to the best way of meeting the general demand for a more regular and thorough public provision for advanced education, not through appeals to legislatures, to be subject to all the risks of overtaxed public bodies, but by a constitutional provision for a fixed, though small, percentage of the income of the State to be set apart for higher education and for all branches of education that ought to be maintained at the public expense, to be expended through the college and university council, made up of state officials and representatives of universities and colleges and institutions of advanced scientific and technical education. Established by law in 1895, it only needs increased power to do its best work.

Well directed public bounty, as President White says, stimulates private bounty. Generous men and women, seeing that the current needs of such institutions were provided by state revenue, would gladly give freely and largely for such special additions as may appeal to them. The alumni of universities will find new inspiration for their activity in giving, advising, and encouraging the growth and prosperity and advancement of their alma mater. Thus, nation, state, alumni and individual grants and gifts would be united to strengthen state institutions and enable them to give the highest literary, scientific and industrial instruction.

The same trend of educated opinion is found in other publication of the highest authority. In the 44th annual report of the Smithsonian Institute, that for 1889, Professor Herbert B. Adams's paper on the state and higher education gives the strongest facts and arguments in support of state aid. He points out that in colonial days Maryland began her educational history by paying a tobacco tax for the support of William and Mary College in Virginia. Vermont appropriated a township of land for Dartmouth College in New Hampshire. New Haven sent corn to the support of Harvard. In later times Michigan gave to the university one twentieth of a mill tax on every dollar of taxable property: Wisconsin one eighth of a mill; Nebraska three eighths of a mill; California one tenth of a

mill; and now the same rule holds in so many states that it may be described as the normal basis for state aid to higher education.

In the proceedings of the National Education Association there are abundant evidences that the leading and recognized authorities on education in this country take the same view.

In the report for 1900, President Swain, then of Indiana University, now of Swarthmore, gave a sketch of the history of the promotion of higher education by the state from early times until the present. He gives forty-five as the number of colleges and universities supported by the state, and points to seven representative state universities—California, Illinois, Kansas, Michigan, Minnesota, Nebraska, Wisconsin.

President Beardshear of Iowa State College of Agriculture, said there were 64 colleges or departments inaugurated by the Act of Congress of 1862, making land grants for the establishment of schools for mechanical and agricultural instruction.

Again at the National Education Association meeting of July, 1901, President Jesse of the State University of Wisconsin, read a paper on the "Function of the State University." He points out the opportunities for collaboration with state boards, bureaus and commissions, with a view to serious study of social and economic conditions.

Today and in and by our own university much is done for the state and the city, but as a matter of grace; make it the university of the state, and state and city would ask for help as a matter of right. Social and economical and legal problems would be attacked and solved. By coöperation with boards of education and state and local superintendents, the university would help to build up schools, from primary to normal, by trained inspectors, skilled examiners, lecturers, practical teachers. Colleges and higher technical schools should be brought into union with the university, all working towards the common end and aim, the best education of the largest number.

The university of the state should be in close touch with all the state boards, bureaus and commissions, the geological survey, the bureaus of health, education, forestry, mines, industries, all the innumerable functions and activities of the state. The university should help in the preparation of laws governing taxation, every

day growing more complex, and in every form of economic instruction, for the benefit of the state in its legislation, and of the plain people. In Pennsylvania, mining, metallurgy, manufacturing, forestry, light, heat and power, are among the living issues that require sound legislation and to prepare it should be one of the functions of the university of the state.

The United States Bureau of Education publishes annually a Bulletin of Statistics of State Universities. These include a directory of state universities and other state-aided institutions of higher education, noting specially those endowed by the federal government under the Morrill Land Grant Acts. These numbered 87, besides 16 agricultural and mechanical colleges for colored students, in the list for the year ended June 30, 1912. There are tables showing the teaching force, the student enrollment, the property and income of the 87 state universities and state-aided institutions.

State universities and state-aided institutions of higher education included in this list, corrected by figures of Professor Maphis' Report, are as follows:

		Income from Mill Tax.
Arizona	3/5 of a mill	32,000
California	22.5/100 of a mill	750,000
Colorado	3/5 of a mill	223,000
Illinois	3 mills	
Indiana	1/10 of a mill	173,000
Iowa	1/8 of a mill	
Kentucky	1/2 of a mill	47,000
Michigan	3/8 of a mill	650,000
	1/10 of a mill	173,000
Minnesota	23/100 of a mill	260,000
Nebraska	1 mill tax rate	411,000
Nevada	1/2 mill tax rate	
New Mexico	65/100 mill tax rate	
North Dakota	1/5 mill tax rate	
	33/100 mill tax rate	
Ohio	17/2000 mill tax rate	92,000
	107/2000 mill tax rate 540.000	360,000
	17/2000 mill tax rate	88,000
Texas	1-3/4 p. c. gross revenue of state	
Utah	7.94 p. c. of 4-1/2 mills on the dollar	
Utah	18.04 p. c. of 4-1/2 mills on the dollar	
Wisconsin	3/8 mill tax rate	664,000
Wyoming	1/2 mill tax rate	24,000

President James of Illinois State University says the legislature of Illinois at its last session (1912) passed a law providing that a tax of one mill for every dollar of assessed valuation should be levied for the support of the university. This will give about two and a quarter million dollars per year, available July 1, 1913. Owing to the provision in the constitution of Illinois that the legislature may not make appropriations for longer than two years, the legislature must appropriate at each session the money represented by this mill tax and labeled for the support of the University of Illinois.

Michigan and Wisconsin provide for the levying of a certain so-called mill tax, three eighths or four fifths of a mill, the proceeds of which are turned over to the board of trustees of the beneficiary institution.

The statistics of state universities and other institutions of higher education partially supported by the state for the year ended June 30, 1912 (*Bulletin*, 1912, No. 33), give a great many details, among them a table of property and income of state universities and other state-aided institutions, showing that there were paid—

	By the State.	By the United States.
To the University of California	1,124,506	80,000
To the University of Indiana	1,918,900	79,938
To the University of Minnesota	2,314,713	80,000
To the University of Missouri	610,093	76,875
To the University of Nebraska	651,318	80,000
To the University of Cornell	478,000	72,000
Ohio { Ohio University, Ohio State University, Miami University }	1,131,778	50,000
To the Universty of Wisconsin	1,552,398	80,000

The same table gives the receipts from the mill tax and other sources of some of the states, as follows:

Colorado (4 institutions)	406,053
Indiana (2 institutions)	259,504
Iowa (3 institutions)	407,200
Michigan (2 institutions)	932,867
Minnesota	689,521
Nebraska	374,163
Ohio (2 institutions)	480,828
South Carolina	114,113

Utah	150,000
Wisconsin	1,103,029
Wyoming	84,000

The same table gives among the many private benefactions to those state-aided universities:

California	566,000
Nevada	150,000
Cornell	1,307,111

The records of these 87 state-aided institutions confirm the belief that private benefactions will continue to supplement in generous measure the state-aided institutions just as these show by their results that they are entitled to individual as well as state help.

Pennsylvania expended in 1912 for—

Department expenses	$ 4,972,538.34
Expense of government	5,390,798.00
Commissions	407,900.00
State institutions	3,342,348.33
Penitentiaries and reformatories	544,378.69
Semi state institutions	685,750.00
Educational	8,737,600.00
Hospitals	2,683,650.00
Homes and other charitable institutions	368,300.00
Miscellaneous	1,059,500.00
	$28,192,763.36

If the appropriations for education were made by the college and university council and those for forestry, mining, etc., by boards or commissions on which were the best experts from the universities and colleges and technical schools and museums, men of scientific attainments, the result would be economy in cost and increased efficiency.

It ought not to be difficult to fix a mill tax for higher education and to devise a plan by which it should be automatically collected and set apart and distributed by the college and university council in such a way as to do the greatest good to the greatest numbers, and at the same time invite a continuance and increase of the individual munificence so characteristic of Pennsylvania.

A bill was presented to the Legislature of Pennsylvania in March

for an automatic distribution of the aid which the state accords to hospitals and charitable institutions; if passed, it would eliminate the methods characteristic of the distribution of state funds by the legislature for purely public charities.

Another bill provides for a charities bureau in the Department of the Auditor General to carry on the duties imposed on the Auditor General and the State Board of Charities.

The purpose of these bills is to make automatic distribution of state revenue to and among hospitals and charities doing the work for the people of the state, on the basis of services rendered, and a method of full returns of receipts and expenditures, with power by inspection to correct extravagance, and to compel economy in expenses of maintenance, and to prevent unnecessary duplication of institutions, but to require of them steady improvement and constant advance in methods and results.

The growing interest and general demand for the mill tax for the support of higher education are shown in recent reports, that for Virginia by Professor Charles D. Maphis, of the University of Virginia; that for Texas by Professor Arthur Lefevre, of the University of Texas, and that for Ohio by President Alston Ellis, of Ohio University. That for Virginia is the report made by a commission to devise a systematic method to meet the demands of higher educational institutions, to prevent educational duplication and consequent financial waste, and to devise stable and systematic methods for the maintenance, management and expansion of these institutions. The report recommends for Virginia one medical school, one polytechnic school, and one university, and a permanent education commission with power to coöperate with the governing bodies of all institutions of higher education in Virginia through representatives.

Professor Maphis has collected and printed the opinions of representatives of the universities of California, Wisconsin, North Dakota, Minnesota, Kentucky, Michigan, Iowa, Illinois, and of the experts of the Carnegie Institute for the Advancement of Education, of New York, and of the Bureau of Education of Washington.

Based on these and other evidence, Virginia is advised to adopt

a mill tax for higher education and with and through it to reorganize its institutions of higher education so that they may grow with the growth of the state and with its income and make return in increased work for the state and its people.

In the college and university council of Pennsylvania the state has a capital piece of machinery for the distribution of the proceeds of a state mill tax for higher education. In that council there are the representatives of the state, the governor, the attorney general, and the superintendent of public instruction, and of the universities, Pennsylvania, Pittsburgh, Lehigh and Bucknell, and of the colleges, Washington-Jefferson, State, Franklin & Marshall, and an eminent citizen representing the Catholic institutions of higher education. With such men that council could be safely entrusted with power to make a distribution of any sum raised by a mill tax, so that it can be distributed to the greatest advantage of all the institutions of higher education in Pennsylvania.

The last report of the Superintendent of Education gives a list of six universities, twenty-nine colleges, four law schools, four dental schools, three pharmacy schools, thirteen normal schools and seven technical schools in Pennsylvania.

The state has created many examining boards for law, medicine, pharmacy, dentistry, veterinary candidates, osteopathy, accountants, and boards for the geological and topographic survey, vaccination, health, mining, etc., and all of them might well be affiliated with the college and university council, which could designate university and college experts to carry on the work.

CLIMATIC AREAS OF THE UNITED STATES AS RELATED TO PLANT GROWTH.[1]

(Plates IX, X, and XI.)

By BURTON EDWARD LIVINGSTON.

(*Read April 18, 1913.*)

Introduction.

The climatic factors which generally determine whether a given kind of plant may or may not live in a certain locality are to be divided into two groups. The first group comprises those factors which tend to increase or to decrease the moisture content of the plant body. They may be termed the moisture conditions of the environment. The second group includes the climatic factors which tend to raise or to lower the temperature of the plant. These are the temperature conditions. A third group of climatic factors includes those tending to increase or decrease the insolation of the plant and hence to promote or retard photosynthesis in green tissues, by which carbon dioxid and water are decomposed with the formation of molecular oxygen and carbohydrate. With these light conditions, however, climatic plant geography has as yet but little to do and this group will not receive attention in the discussions which follow.

Before plant geography can pass beyond its qualitatively descriptive phase, the moisture and temperature relations that obtain between plants and their surroundings must be subjected to examination much more quantitative than has heretofore been attempted. As in other similar instances, definite knowledge of this complex set of relations can be reached only through measurements of the things that are to be related. It thus appears that, for those chapters of plant geography and of scientific agriculture which have to do with climatic conditions, it will presently be found requisite to

[1] Botanical contribution from the Johns Hopkins University, No. 32.

measure both the plants dealt with and their environmental conditions. Since both plants and their surroundings are always changing, it is essential that our measurements take the form of summations or integrations. It is therefore first incumbent upon us to find means of integrating or summing the various fluctuating conditions, within and without the plant body, that determine the development of the organism and that decide whether it can exist at all in any given set of surroundings.

Measurement and summation of conditions within the plant.

Our very meager knowledge of plant dynamics would render quite hopeless, for the present, any attempt to integrate the qualities, intensities and durations of physiological processes, were it not for the fact that the plant itself furnishes at any instant a very clear and unequivocal summation of the effects of all the processes which have gone on in its body during its previous developmental history. This fact furnishes the criterion by which comparisons have usually been made between the growth processes of different kinds of living things. The amount of growth accomplished during a given time period may be determined by weighing the crop or some portion of it, a method commonly in use in agricultural studies. Another method, employed mainly by phenologists, has been to determine the length of time which may elapse during certain developmental phases of the organism. Thus may be determined the length of the time period that intervenes between seed germination or the first swelling of lead buds, and flower production or the ripening of fruits. Still more simple and more easily applied is the method which merely determines whether or not given plant forms are able to carry out their life cycles under the environmental conditions of certain localities. For the positive answer to this question mere observation frequently suffices, for its negative answer, experimentation, or at least instrumentation, is necessary. If a plant form is observed as thriving year after year and generation after generation in a certain locality, it is, as has been mentioned elsewhere, no less than redundant to point out this as an "adaptation"; but if the given form is not to be observed in this locality, the most direct and final way to

determine whether or not it can thrive there, is actually to make the experimental test.

Frequently a simple inspection of the plant dealt with, or the approximate measurement of certain of its characteristics, may suffice for an indication of its ability to withstand the water-withholding or water-extracting power of the environment. Thus, it has long been appreciated that the ability of a plant to thrive under arid conditions is often indicated by its observable physical structure. The power of an organism to withhold moisture from an arid environment seems to be closely, and usually directly, connected with structural characters which can be recognized at sight, and, on the basis of this principle, ecologists have classified plants into xerophytes, mesophytes and the like. Of course this classification must be subjected to a much more definitely quantitative treatment than the one now generally employed, that of mere observation and personal judgment, before ecology can begin to partake of the characters of an exact science. For such a resurvey of the moisture-retaining powers of plants we have now at least two practicable and fairly quantitative methods[18] besides the directly experimental one of trying various plant forms under various climatic complexes. This is not the place to enter into a consideration of these methods, but it should be emphasized that it now appears to be possible, within a single period of twenty-four hours, to determine with considerable accuracy the position of almost any plant individual in what might be termed an absolute scale of xerophytism, as far as the water-withholding power of its aerial parts is concerned.

For the study of the effects of temperature conditions within the plant, no means is yet available excepting that of direct experiment. In one way the problem here met with is simplified by the well-known fact that plant temperatures practically always follow very closely the temperatures of the surroundings. In attempts to determine the relations between temperature and the various plant processes, it is therefore only necessary to know the effective temperature condi-

[18] Livingston, B. E., "The Resistance Offered by Leaves to Transpirational Water Loss," *Plant World*, 16: 1–35, 1913. Also references there given.

tions of the environment and it is seldom requisite to study the temperature of the plant body separately.

The ability of a plant to withstand unfavorable temperature conditions, quite unlike its ability to withstand adverse conditions of the moisture relation, is not at all indicated by structural characteristics. It is absolutely impossible by mere observation or by any morphological study of a plant, to find a basis even for a rational guess as to the temperature conditions to which the organism may be fitted. Furthermore, no method but that of direct experimentation has been devised, and none seems likely to be forthcoming, by which plants may be studied with regard to their temperature requirements, and the appreciation and interpretation of direct experiment is here so extremely complex that scarcely any attempt has thus far been made in this direction. The result is, that, while we are well aware that temperature conditions are fully as important as those of moisture, in determining plant development and distribution, yet we are without any really quantitative knowledge of the heat relation.

Before such quantitative knowledge can be attained it will be necessary that there be made available somewhere a laboratory so equipped that all of the main conditions of plant growth may be controlled and altered at the will of the experimenter. The need of such a laboratory has been emphasized by A. de Candolle and again by Abbe,[2] who also quotes de Candolle, but, so far as I am aware, no serious attempt has ever yet been made to procure facilities for adequate experimental study of the range of conditions which various plant forms may be able to withstand. The value of such a laboratory to scientific agriculture cannot be overestimated.

For both the temperature and moisture limits of plant activities, a kind of rough and qualitative experimentation has studied the growth of the same variety of plant in different localities or of different varieties in the same locality, and has drawn volumes of vague and more or less discordant conclusions without adequate measurement either of the plants employed or of the climatic conditions to which they have been subjected. This sort of experimentation is

[2] Abbe C., First report on the relations between climates and crops. U. S. Dept. Agric. Weather Bureau Bulletin 36, 1905. See especially p. 23.

very common to-day, especially among agricultural institutions, and considerable practical information is no doubt resulting therefrom. In this agricultural work, however, as also in the observational studies upon natural vegetation, with which plant ecologists are so generally engaged, the physiological characters of plants are determined almost solely with reference to the locations at which they grow. Thus, seedsmen, to describe the physiological properties of the plants with which they deal, must name the regions in which these plants succeed. "A greatly approved variety among the truck gardeners of Long Island," "one of the most successful earlies throughout the South."—so run such trade descriptions.

Measurement and summation of environmental conditions.

When we describe the physiological capabilities of a given strain or species by stating the geographical region in which it thrives, we are of course employing the environmental conditions as a unit for measuring and defining the internal ones. Valuable as this sort of definition undoubtedly is, it falls far short of perfection, even for practical purposes. The climatic conditions of any locality vary from day to day throughout the year and their annual march is never the same for different years. An agricultural plant that proves very successful for one season in a certain place may be a complete failure for the following year. It is clear, therefore, that we must seek methods for describing climatic conditions, other than their simple reference to certain geographical regions. If such methods can be devised, even though we may have no better ways of characterizing our plants than are already at hand, it should become possible to compare the environmental conditions of different regions, and plant geography, as well as scientific agriculture, should be greatly advanced.

Methods and data.

Turning now to the consideration of the methods which are at hand for comparing climates, we are struck with an amusing fact; the most intelligible and most widely used way to do this is to characterize the climatic conditions of any region in terms of the kinds

of plants and animals which thrive there. The sage-brush is a plant with physiological characters such that it thrives best in the temperate arid regions of North America, and the climate of these regions is such as to render sage-brush the dominant and characteristic form of plant life. So we reason in a circle and arrive nowhere.

There are, however, instrumental methods more ideal, if not more satisfactory, by which climates may be compared. Thus the averages or means of temperature, precipitation, humidity, etc., of the meteorologists and climatologists, give numerical data which are, in a way, descriptive. It appears, indeed, that means or averages of the climatic data which have been and are being accumulated throughout the world should furnish a numerical basis for distinguishing between different climatic areas, and this basis has of course been employed by climatologists for many years. Ecologists and agriculturists have frequently made use of such climatic means and have so described the climates with which they have had to deal. But if you will look over any of the recent ecological papers you will find that the definition of climates has not gone very far. Usually a section of such a paper is devoted to the characterization of the climates of the areas considered, but the quantitative part of this section is little more than a mass of unrelated figures; out of these the author himself seems to make no serious attempt to draw generalizations that may be related to the corresponding vegetational areas.

We are thus confronted with a state of affairs which is far from satisfactory. The weather services of the world are expending vast amounts of wealth and energy in accumulating, year by year, observational statistics bearing upon the various climatic areas. These statistics are largely used for weather prediction and for the purposes of theoretical meteorology. It seems that quantitative climatic descriptions must lie hidden somehow in these enormous masses of figures, but the plant geographer, whether agriculturist or ecologist, has thus far been able to derive therefrom but a very small amount of applicable information.

It seems to me that the reason for this state of affairs is a double one: first, the climatological observations of our weather services

have been planned and are carried out mainly not for the study of climate as it may influence plant growth but for the study of meteorology and climatology and for weather prediction; second, the methods now employed for handling the observational data after they have been obtained are not well suited to the study of the climatic relations of plants. To make these propositions clear, we may consider the work of the United States Weather Bureau, this work being familiar to all of us and having a direct bearing upon the problems of plant distribution as I have been led to attack them. Although the Weather Bureau is officially a part of the national Department of Agriculture, being one of the largest bureaus of that department, its main activities have neven been primarily directed towards the relation between agriculture and climatology. Weather prediction and weather history seem to have been almost the sole scientific aims of the organization up to the present time. The student of plant activities will find no fault with these aims, but he may wonder how it has come about that an agricultural bureau has so thoroughly ignored what we must regard as by far the most important relation which exists between human welfare and climate; that is, the relation between plant growth and the climatic features of plant surroundings.

As to the making of climatic observations, it is clear that observatories in the rural districts are the only ones whose records are properly available for our present purposes. It is a curious fact which speaks for the political or commercial rather than scientific nature of our Bureau's organization, that the best equipped observatories in this country are generally located in large cities, and usually high in the air. As the population of the United States has increased you may note a somewhat parallel increase in the average distance of the climatic observatories from the ground. This of course ought not to be. If political and commercial interests demand observatories in the urban districts the records from these should be treated only as special studies of special conditions. It is interesting to note that the charts of Day's[3] recent bulletin upon frost data have

[3] Day, P. C., "Frost Data of the United States," etc., U. S. Dept. Agric. Weather Bureau Bulletin V, 1911.

been compiled, as the author states, wholly from the observations of rural stations. The requisite stations must be, however, in the open country, and not even in small towns.

Furthermore, the geographical distribution of Weather Bureau stations in the United States is anything but rational. Being located mainly in large cities, these stations cluster thickly east of the Mississippi River and are widely separated in the western half of the country. Such an arrangement has, no doubt, its political, commercial, financial and historical reasons; nevertheless, it is scientifically quite the opposite of rational, for climatic gradients are gentle in the east and very abrupt in the west.

For the purposes of the student of vegetational-climatic relations, the actual observations might be greatly improved. As far as the temperature conditions are concerned, the observational methods are fairly well worked out for the present. In the future we shall need a thermo-integrator, the indications of which may bear some at least empirical relation to plant growth, but such instruments remain to be devised. As has been pointed out, the moisture conditions of the environment affect the activities of a plant through their influence toward increasing or decreasing its water content. Now, most plants—and *all* agricultural plants—derive water mainly from the soil and lose it mainly to the air. It is thus clear that, with proper consideration of soil conditions, the data of precipitation should furnish us with a valuable criterion for comparing climatic areas. Precipitation is easily measured and our information in this connection is fairly satisfactory. For the other factor of the moisture relation of plants, however, namely the power of the aerial surroundings to extract water from the plant, the climatic data which have been accumulated in this country furnish practically no information. The available measurements and averages bearing on this point are those of relative humidity (a somewhat artificial abstraction), pressure of water vapor, wind velocity, temperature and sunshine intensity. While the present method of measuring rainfall is self-integrating and leaves little to be desired in the way of improvement, the methods employed in measuring the water-extracting factors just mentioned all involve artificial manipulations before any

climatic characteristics can be derived therefrom. Indeed, the sunshine data furnished by the weather observatories is not even quantitative in any adequate sense.

In the face of these difficulties ecology has been forced to turn entirely away from the available meteorological data. It is apparent at once that the water-extracting power of the aerial environment is effective through the evaporating power of the air and the intensity of sunlight. The sunlight factor appears frequently to be of comparatively little importance in the climatic moisture relation, though its effects in removing water from moist objects such as plants can now be measured and automatically integrated with considerable readiness.[4] The evaporating power of the air (a complex of the effects of vapor pressure and wind movement) appears, on the other hand, to be generally of prime importance. This fact has long been recognized and meteorologists outside of the United States have accumulated a vast amount of information upon evaporation as a climatic factor.[5] Meeting with difficulties in the standardization of atmometers, many workers have turned their attention to attempts to derive a formula by which evaporation might be computed from the meteorological factors usually measured. An enormous amount of work has been done in this line, but the results are of little value for climatological purposes. At the same time various students of climatology and of plant activities have devised numerous forms of atmometers, for measuring and automatically integrating the evaporating power of the air directly. Since the latter is a very complex factor, it comes about that data from different kinds of instruments cannot be readily reduced to a common standard, so that there has been some hesitation in making evaporation measurements a general feature of climatological work. It is nevertheless true that, for our present purposes at least, all that is required is that some one form

[4] Livingston, B. E., "A Radio-atmometer for Measuring Light Intensities," *Plant World*, 14: 96–99, 1911; "Light Intensity and Transpiration," *Bot. Gaz.*, 52: 418–438, 1911.

[5] In this connection see Livingston, Grace J., "An Annotated Bibliography of Evaporation," *Mo. Weather Rev.*, 36: 181–6, 301–6, 375–81, 1908; 37: 68–72, 103–9, 157–60, 193–9, 248–52, 1909. Also reprinted and repaged 1–121, 1909. The subject has very recently attracted much more attention than formerly, especially from agriculturalists and ecologists.

of atmometer be generally adopted, and many weather services are at present furnishing data upon evaporation as well as upon the other climatic factors more commonly recorded. On account of various difficulties arising from the use of a free water surface for measuring evaporation, the most valuable instruments now available determine the evaporation rates from the surface of an imbibed solid, such as bibulous paper or porous porcelain. For plant ecology the porous cup atmometer[6] appears to be the most satisfactory of these instruments, and it seems to be rapidly rising in the esteem of agriculturists and others who are interested in this line of study. This instrument has the advantage, for our purpose, that its evaporating surface is so exposed as to be fairly comparable to the evaporating surfaces of plants.

The only systematic information which the United States Weather Bureau has furnished upon the geographical distribution of evaporation intensities is comprised in the report of Russell's[7] studies. This author employed Piche atmometers at nineteen stations and derived a formula from the results thus obtained, by which the monthly evaporation rates for many other stations were derived. His operations extended over a single year, from July, 1887, to June, 1888, and a very valuable chart of evaporation in the United States resulted therefrom.

During the summers of 1907 and 1908 I carried out a comparative study of evaporation intensities throughout the United States, under the auspices of the Department of Botanical Research of the Carnegie Institution, using the standardized porous cup atmometer.

[6] On the porous clay atmometer, see:

Babinet, J., "Note sur un atmidoscope," *Compt. Rend.*, **27**: 529–30, 1848. Marié-Davy, H., "Atmidomètre à vase poreaux de Babinet," *Nouv. Met.*, **2**: 253–4, 1869; Mitscherlich, Alfred, "Ein Verdunstungsmesser," *Landw. Versuchsstat.*, **60**: 63–72, 1904; also **61**: 320, 1904; Livingston, B. E., "The Relation of Desert Plants to Soil Moisture and to Evaporation," Carnegie Inst. Wash. Publ. 50, Washington, 1906; "A Simple Atmometer," *Science*, N. S., **28**: 319–20, 1908; "A Rotating Table for Standardizing Porous Cup Atmometers," *Plant World*, **15**: 157–62, 1912; also other literature there referred to.

[7] Russell, Thomas, "Depth of Evaporation in the United States," *Mo. Weather Rev.*, **16**: 235–9, 1888.

The results of these studies have been published[8] and furnish, for fifteen weeks only, the second chart of evaporation which has ever been prepared for this country. It is interesting to note that a fifth of a century elapsed between these two studies, and that nothing further has yet been attempted.

Judging from the results already obtained, it appears that the simple measurement and automatic summation of the evaporating power of the air for the various climatic areas furnishes as satisfactory a measure of the water-extracting power of the environment as the student of plant relations can hope for from a single condition, and the future development of this branch of science will depend largely upon whether or not comparative evaporation records may become available.

Treatment of observational data.

The frostless season.—In the preceding paragraphs have been considered the most requisite methods for obtaining climatic observations. We shall now turn our attention to the application of these observations after they have been obtained. It is the custom of meteorologists to derive from the actual observations, daily means, monthly means and annual means, and to give most attention to the latter. Now, for the purposes of vegetational-climatic investigations, it appears that none of these means offers much assistance. In the determination of plant activities, at least in the majority of cases, the controlling climatic factors are primarily effective only during the growing season, and I am convinced that this season should form the basis of a large part of the manipulation of climatic records, which which we are here interested. As an approximation of the vegetational growing season, for general use throughout our country, it seems most promising to adopt the length of the frostless season, the number of days intervening between the average dates of the last killing frost in spring and the first in autumn. That other duration factors will be required in many cases is not to be doubted,

[8] Livingston, B. E., "A Study of the Relation between Summer Evaporation Intensity and Centers of Plant Distribution in the United States," *Plant World*, 14: 205–22, 1911.

but this appears to be far more broadly applicable than any other. The actual data of mean length of the frostless season in the United States have never been published, but Day's chart (already referred to) presents a general view of the range in length of this period which this country affords. Data corresponding to those from which Day's chart of the frostless season was compiled have been deduced from the average dates of last and first killing frosts as given in the 106 Sumaries by Sections[9] published by the Weather Bureau. These deduced data have been used in deriving the other climatic indices considered below.

Temperature integration.—The mean length of the frostless season is of course primarily a temperature condition, but it tells us nothing of the normal temperatures which may prevail within the period designated, only that killing frosts do not normally occur. In order to be able to relate the temperatures of the frostless season to plant activities it is thus obvious that we shall need to sum or integrate the temperatures over the period of active growth. As has been said, the mature plant itself is to be regarded as a summation of all of the accelerations and retardations which have occurred during its life, so that our integration of temperatures should attempt to consider these, not merely as they affect our thermometers, but rather *as they affect plants.* This is, however, practically impossible until we have at our disposal a much larger fund of information concerning the general relation of plant activities to temperature, and such information is not apt to be forthcoming until such time as the laboratory for controlled conditions, mentioned above, may become a fact instead of a mere dream. Various procedures of temperature integration have been devised by different writers and appear to be more or less valuable in this connection, but the physiological basis for such procedures remains still to be established. Under the circumstances, it seems best here to give attention to but a single one. This is the method of direct summation of the daily normal means throughout the period in question.

[9] "Summary of the Climatological Data of the United States, by Sections," U. S. Department of Agriculture Weather Bureau. No date. The 106 pamphlets appear to have been prepared about 1909–10. The data extend for the most part through 1908 or 1909.

Bigelow[10] has given us the daily normal temperatures throughout the year for 177 stations well distributed over the country. This excellent piece of work has laid the foundation for many kinds of climatological study that would otherwise be impossible. The data are generally based on an observation period of about thirty years and may be regarded as quite as reliable as any other data that we now have. In summing the daily normal temepratures for the days within the average frostless season, for each one of the numerous stations, some temperature must be assumed as a starting point. I have taken 32° F. The results of such summations may be termed average or normal temperature summations, above 32° F., for the frostless season at the various stations.

The method here used is somewhat similar to that employed by Merriam[11] in his well-known study of the temperature relation in the United States. This author did not use the average length of the frostless season, however, and his manipulations differed from my own in other details. The general method of summations is not at all new, having been long employed by phenologists.

When we plot the temperature summation indices upon a map and draw isoclimatic lines in the usual way, there results a chart which presents the country divided into zones or bands. Such a chart is shown by the dotted lines of plates IX., X., and XI. Without entering into details, it is at once seen that the temperature summation zones cross the continent in a generally west-east direction, being southwardly displaced in the regions of the two mountain systems and also to some extent along the Pacific seaboard. Practically all of the area of the United States is characterized, according to this chart, by normal temperature summation indices ranging from 3,000 to 13,000. The southern half of the Florida peninsula exhibits still higher indices.

Integrations of the moisture relation. 1. General considerations.—While temperature furnishes us a single means of studying

[10] Bigelow, F. H., "The Daily Normal Temperature and Daily Normal Precipitation of the United States," U. S. Dept. Agric. Weather Bureau Bulletin R, 1908.

[11] Merriam, C. H., "Laws of Temperature Control of the Geographic Distribution of Animals and Plants," *Nat. Geog. Mag.*, **6**: 229–38, 1894.

both the tendency of the plant to gain heat and its tendency to lose heat, we find no such simple climatic factor to use in studying the conditions which tend to add water to the plant or to remove it. As has previously been mentioned, the ordinary plant derives most of its moisture supply from the soil and loses water to the air. The possible rate of moisture supply to growing plants is thus determined by the resistance of the soil to the movement of moisture into plant roots. While the physical properties of the soil play an important part in this connection and while these vary from place to place, the amount of water present in the soil is also of primary importance. This depends, for any particular soil and in the majority of cases, upon precipitation, and the measurement of this climatic factor furnishes us, as is commonly recognized, with a criterion of considerable value in the comparison of climatic areas. While the distribution of rainfall throughout the period of the plant's activities is fully as important as its amount, I shall give attention in this paper only to the latter.

It has already been emphasized that the evaporating power of the air is the main climatic feature in the control of water loss from plants, as from other moist objects. If we add to this the water-extracting or desiccating power of the sunshine we have an exceedingly satisfactory measure of the water requirements of plants, for most of the water absorbed by ordinary plants is lost by transpiration. Here also I shall consider only the question of the mean evaporating power of the air throughout the period of the frostless season.

If we assume for the moment that soils are all alike in their physical properties, and if the moisture supply of plants be proportional to precipitation while the water loss is proportional to the evaporating power of the air, some relation obtaining between these two factors should be a direct measure of the vegetational water relation. Unfortunately for our study, the assumptions above made, especially the one regarding the physical properties of soils, are very far from true; yet certain physical types of soil are found in every one of the climatic areas which we are apt to encounter, and for any such type the relation just referred to should be of great value.

Thus, heavy clays occur commonly throughout the United States and the moisture relation of plants growing thereon may be approximately proportional to the relation of precipitation to evaporation. A similar proposition may hold for sandy soils. It is, however, to be noted that a sandy soil and a clay soil under the same climatic conditions ought not to be expected to possess the same power of supplying moisture to plants.

The relation of precipitation to evaporation was first emphasized as a climatic factor influencing vegetational distribution in the United States by Transeau,[12] who constructed a very interesting and valuable chart of the eastern portion of our country on the basis of the ratio of mean annual precipitation to the annual evaporation obtained by Russell for a single year. Another, and in some ways more satisfactory relation between rainfall and evaporation is the *difference* between these factors, precipitation *minus* evaporation. I have tested this as extensively as our extremely meager data on evaporation will allow. In the present paper attention will be confined to this index of difference for the frostless season.

We now turn our attention to three examples of the quantitative study of the moisture relations of the United States, resulting in the means of precipitation, of evaporation and of the difference between these two for the frostless season.

2. Amount of precipitation during the frostless season.—Bigelow has given us, by means of very ingenious and elaborate methods, a table showing the daily normal precipitation for each of 177 stations in the United States, and it is upon this valuable work that I have based all of my quantitative studies of rainfall. In the present instance, wherein the normal distribution of precipitation during the year will receive no attention, I have merely determined the average normal daily precipitation at each station throughout the frostless season. This gives a precipitation index which is at once seen to be definitely related to plant activities. Stations with high precipitation indices are situated in the humid regions, those with low indices are in the arid regions.

[12] Transeau, E. N., "Forests of Eastern America," *Amer. Nat.*, 39: 875–98, 1905; "Climatic Centers and Centers of Plant Distribution," Mich. Acad. Sci. 7th Ann. Rept., 1905.

When these indices are placed upon a map and isoclimatic lines are drawn in the usual way, we have the chart which is shown in full lines in plate IX.[13] The data are in terms of hundredths of an inch per day and their range of magnitude is from less than two to over sixteen hundredths. This is not a proper place for detailed discussion, but it is at once obvious that the precipitation lines of this chart tend strongly to take a north-south direction, thus crossing our isothermal lines and dividing the country into irregular climatic areas each of which might be defined by the use of these two systems of lines. As has been stated, the data from which both temperature and precipitation charts have been constructed are relatively very satisfactory, and it may be surmised that the combination chart here presented is fairly reliable as a general picture of the climatic conditions of the country as measured according to the method here set forth.

3. Amount of evaporation during the frostless season.—Russell's data on evaporation in the United States are for but a single year, and that not a calendar one. The probability of error introduced by assuming these data to be normal is very great, yet, as has been emphasized, these are the only data yet available, and we must either employ them or follow the custom of our Weather Bureau and ignore the important subject of direct evaporation measurements entirely. More to illustrate the value of evaporation records than with any thought that the details of the present study may be free from large error, I present here the results of an approximate determination of the mean depth of daily evaporation for the frostless season. It is to be noted that the data for the earlier months of the frostless season are from the summer of 1888, while those for the later months are from that of 1887, an unsatisfactory state of affairs made necessary by the exigencies of Russell's study.

Russell's published data are given by months, and, since the

[13] It is to be remarked that this and the two following charts attempt no more than an approximation to normal conditions. The lines are so placed, however, as to represent the data as these have been obtained. Where no stations are present topography has been used as an indication of the probable position of the lines. All of the data here employed will be published elsewhere.

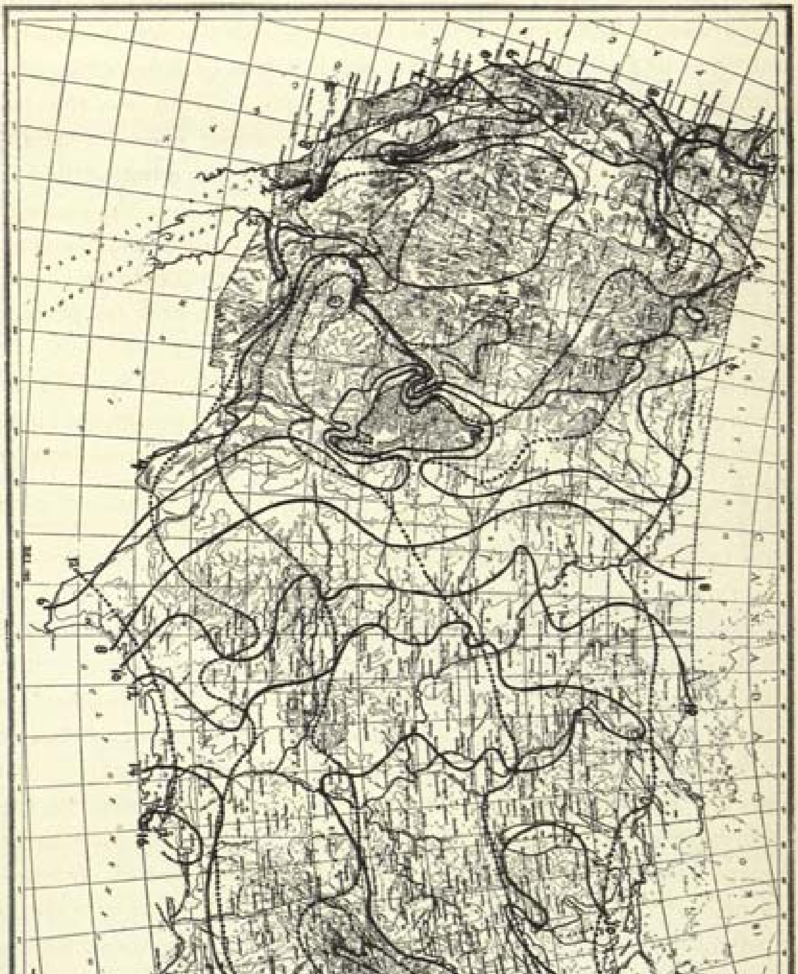

PLATE IX. Chart showing climatic mosaic formed by two systems of isoclimatic lines. Broken lines represent temperature summation indices (in thousands) and full lines show precipitation indices (in hundredths of an inch per day) for the mean frostless season.

PLATE X. Chart showing climatic mosaic, as in plate IX, but the isoclimatic lines of temperature (broken) are here combined with a system of lines (full) representing evaporation indices (in hundredths of an inch per day) for the mean frostless season.

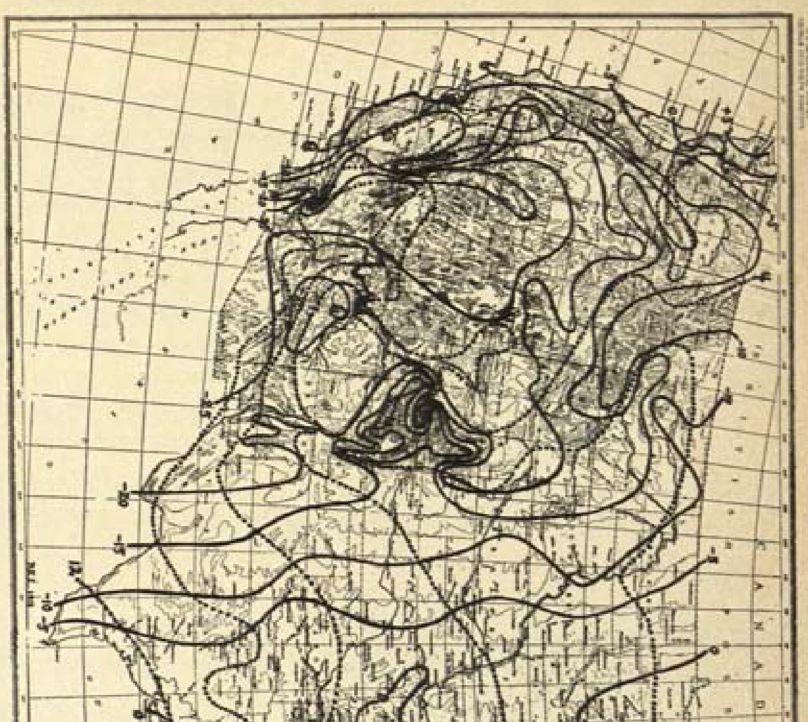

PLATE XI. Chart showing climatic mosaic, as in plates IX and X, but the isoclimatic lines of temperature (broken) are here combined with a system of lines (full) representing the differences between precipitation and evaporation indices (in hundredths of an inch per day) for the mean frostless season. Stations having two indices equal are on the zero lines. Plus areas have higher precipitation than evaporation indices, minus ones have lower.

normal frostless season rarely begins or ends with a month, it has been generally necessary to interpolate values for fractions of a month at the beginning and end of each season. The evaporation indices obtained are in terms of mean daily loss in depth from a small pan of water, in hundredths of an inch. When these indices of daily evaporation are plotted on the map and the isoatmic lines are drawn, there results the chart which appears in full lines in plate X. Here, as in the case of the precipitation chart, we observe a marked tendency of the lines to take a north-south trend and thus to cut the temperature lines so as to make of the country a climatic mosaic somewhat similar to that presented by the preceding chart. The range of daily evaporation appears here to be from less than ten to more than thirty-two hundredths of an inch.

4. Moisture excess or deficit during the frostless season.—Determining, for each station considered, the difference between the indices of precipitation and of evaporation, it is found that these differences are approximately zero for some stations and are either positive or negative for others. If the differences thus obtained are placed upon a map it is possible to draw isoclimatic lines again dividing the country into areas (full lines, plate XI.). As has been mentioned, these areas or zones may be tentatively taken to be characterized by the conditions of the plant water relation. The data are again in terms of hundredths of an inch per day, during the frostless season. They range from a negative value of 30 to a positive one of more than 5. Almost the entire country is seen to have a moisture deficit (*i. e.*, evaporation is greater than precipitation, as here measured). Only the extreme northwest, a small area in Missouri, and a narrow zone near the eastern half of our northern boundary, continued southward along the Atlantic seaboard and westward along the margin of the Gulf of Mexico as far as Texas, exhibit a moisture excess. Of course the highest deficits occur in the most arid areas. These lines of moisture excess or deficit are seen also generally to possess a north-south trend. Here again the country is subdivided into areas by the crossing of temperature and moisture lines and the various areas are susceptible of definition by means of these lines. The unsatisfactory condition of the evapora-

tion data upon which the present study has necessarily been based renders this chart of doubtful accuracy as a picture of normal conditions, but it serves its purpose admirably, of illustrating something of what may be possible in the way of quantitative vegetational climatology, whenever the attention of climatologists may be seriously attracted to this aspect of the application of their science.

The relation of vegetation to climate.

In order to study vegetational distribution as this is related to such climatic areas as have been brought out on the charts here presented, it is of course necessary to have recourse to corresponding charts showing the distribution of natural or cultivated plants. It would be beyond the scope of the present paper to attempt to show by examples how the area occupied by any plant may thus be climatically characterized, and such examples will not be brought forward here. It may be repeated, however, that the obvious and visible characters of the great vegetational types (such as those of conifer and deciduous forest, grassland and desert), while exhibiting an unequivocal relation to moisture conditions, still bear no relation to conditions of temperature. Only when the thus far practically insensible physiological characters of plants may be considered will it become possible to relate their distribution to temperature conditions.

The student of the climatic relations of plants must bear in mind the extremely complex nature of the conditional complex which must determine plant distribution. Aside from climatic conditions, the nature of the soil usually plays an important part, as has been emphasized. Furthermore, numerous mechanical and other factors may have determined, in the past, whether or not a given plant form may ever have reached a specified locality. Because of this historic factor in plant geography, the climatic and soil conditions cannot be taken as limiting distribution unless we are certain that the plants thus limited have been tried throughout the region under discussion. After they have been tried the historic factor vanishes from our consideration. Nevertheless, without recourse to this removal of the historic factor from the argument, it is still quite possible and logic-

ally sound to study the relations which obtain between vegetational areas and climatic areas. This sort of relation is truly only a spatial one, however, and must not be assumed to be causal. The probability that such a relation is a causal one is of course increased as it is found to hold in a large number of cases. With agricultural plants the historic factor need not be considered; the actual experimental test as to whether a given form will thrive in a given area is somewhat readily made and the results are clear enough.

Johns Hopkins University,
April 18, 1913.

SOME DIFFRACTION PHENOMENA; SUPERPOSED FRINGES.[1]

By CHARLES F. BRUSH.

(*Read April 19, 1913.*)

Fresnel observed that diffraction fringes, outside the shadow, are not affected by the thickness or shape of the diffracting edge so long as the latter is smooth and straight; and cited, as an instance, the back and edge of a razor, which gave identical fringes under the conditions of his experiment. Presumably he observed the fringes as developed several decimeters, or even meters, from the diffracting edge in the usual way.

I have found, however, that when the fringes are observed within a millimeter or two of the diffracting edge, by means of a microscope, they are very greatly influenced in brightness and sharpness by the contour of the edge.

In most of my experiments I have used cylindrical edges in order that their shape and curvature might be accurately known. I have used fine wires grading up from 0.02 of a millimeter in diameter to fine needles, thence to medium and large needles, and small, medium and large brass rods and tubes, always with a smooth surface. The fine wires and needles were screened on one side to confine diffraction to the other side only.

In the diagram of my apparatus *A* represents the source of light, which conveniently may be a short section of a tungsten lamp filament; *B* is a spectrometer slit parallel with the lamp filament and very nearly closed. *C* is the diffracting screen located 15 or 20 cm. from the slit, with its edge adjusted parallel with the slit by turning the stage of the microscope *D*. *D* is a microscope provided with a 5.0 or 2.5 cm. objective and a strong eyepiece giving a magnifying

[1] Presented in preliminary form before The American Asociation for the Advancement of Science, December 30, 1912.

power of 100 to 200 diameters. The focal plane of the objective is usually adjusted near the diffracting edge as indicated by the dotted line, and it must be borne in mind that this is where the fringes are seen.

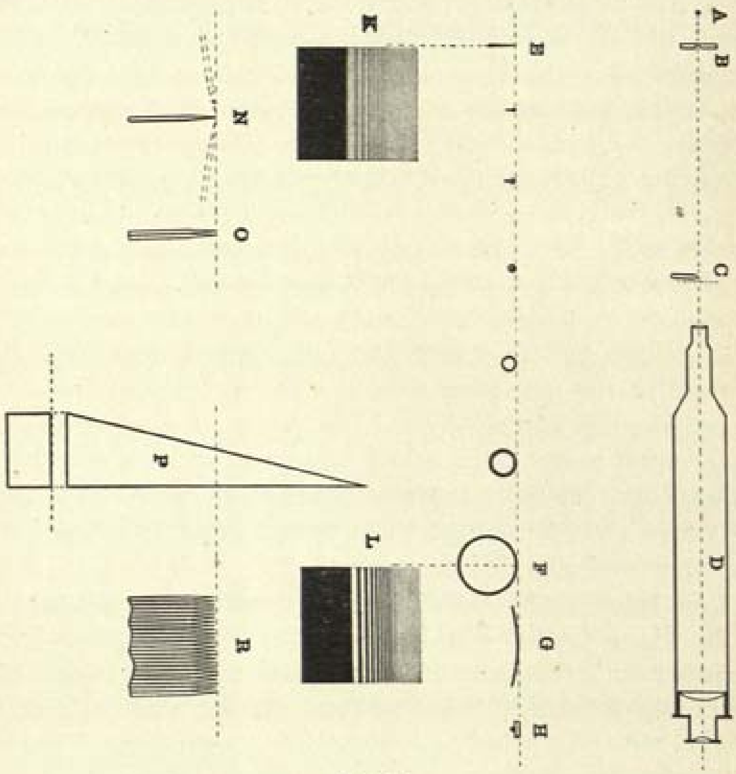

FIG. 1.

From *E* to *F* a series of cylindrical edges of progressively increasing radii is indicated. *E*, however, is a sharp razor blade, and the fringes projected by its edge are shown, greatly magnified, at *K*. They are weak, few in number and hazy in outline; but these conditions are not due to any irregularity of the edge. When a fine wire is used the fringes are distinctly better. Every time the radius of the cylindrical edge is doubled, the fringes are unmistakably brighter and sharper. *L* indicates the fringes produced by the cylin-

der F, of 22 mm. radius. They are very bright and sharp, and nearly free from color. From 12 to 15 may be seen. The curved plate G, of many cm. radius, gives fringes perceptibly brighter than F.

When the radius of the cylindrical edge is rather less than one millimeter, all fringes disappear if the focal plane is advanced sufficiently to coincide with the median plane of the edge, as would be expected. But when the radius is a millimeter or more, sharp, narrow fringes may be seen with the focal plane in this position, and these fringes grow broader and more numerous as the radius of the diffracting edge is increased. Evidently they are formed by elements of the cylindrical edge lying beyond (toward the light) the element in the median plane. If, now, the focal plane of the microscope is slowly advanced toward the light, these fringes slowly retreat behind the edge without greatly changing their spacing. They remain visible for some distance behind the edge because the angular aperture of the microscope objective enables the observer to see around and beyond the edge to some extent. Upon reversing the movement of the focal plane the fringes move laterally from behind the edge until the median plane is reached, when the lateral movement stops abruptly and the fringe pattern simply broadens out as the retreat of the focal plane continues.

I am led to the belief that the very greatly enhanced brightness of the fringes produced by the diffracting edge of large radius as compared with the razor edge, is due to the superposition of a number of diffraction fringe patterns which are almost, but not quite, in register. This view is supported by experiments illustrated in diagrams N and O.

N shows a razor blade greatly enlarged. It makes not the slightest difference in the fringes whether the blade is in the full line position shown, or in either of the dotted line positions, the essential condition being that the light undergoing diffraction shall not strike the beveled side of the blade.

At O two razor blades are shown clamped together with their edges as close as possible (about 0.2 mm.), and as nearly as possible in the same plane. The combination is adapted to be rotated slightly about the line of one of the edges as an axis by means of a tangent

screw, so that the edge nearer the light may be withdrawn very slightly below the plane of the incident beam which strikes the other edge. When this adjustment is just right the brightness of the one-blade fringes is approximately doubled, clearly indicating that two superposed fringe-patterns are formed. It appears that twice as many elements of each wave front are affected.

We may regard the cylindrical diffracting surfaces as consisting of a great many parallel elements, each acting as a diffracting edge and producing its own fringe pattern which is superposed on those of the other elements. This superposition of fringes is not apparent when they are viewed in the usual way, *i. e.*, in a plane far removed from the diffracting edge, because nearly all of the patterns have their origins so far behind (toward the light) the tangent element of the edge that they are hidden by it. The method of viewing the fringes herein described, however, enables the observer to see these hidden fringe patterns, as already pointed out.

Measurements, the details of which need not be gone into, show that in the case of the cylinder *F*, of 22 mm. radius, the width of the strip of surface involved in producing the best and brightest fringe pattern is about 1.5 mm., though 0.9 mm. gives all but the extreme lines. Smoking the surface of the cylinder makes very little difference in the brightness of the fringes, and the slight loss observed is accounted for by the roughening of the surface.

Careful eyepiece micrometer measurements of the spacing of the fringes formed by the razor edge *E*, and a cylinder of small radius agree perfectly with the theoretical spacing of diffraction fringes. But with the large cylinder *F* (and still more so with the curved surface *G*) the spaces diminish less rapidly toward the outer margin of the pattern and the outer fringes lose their sharpness, because the many superposed fringe patterns which form the composite pattern observed are not quite in register; so that beyond 12 or 15 fringes many maxima and minima so far coincide that no more lines are seen.

The reason why the numerous patterns are not perfectly in register becomes clear when we consider that they have their origins at different distances from the focal plane of the microscope, and

hence are seen spread to different extents. This discrepancy is partially offset by the lateral displacements of the origins due to the curvature of the diffracting surface, and the net result is that the composite pattern seen is brightest and sharpest in a few fringes only, the position of which may be shifted to some extent by shifting the focal plane.

Diagram *H* shows the end of a glass plate with optically plane polished upper surface 12 mm. wide, bounded by straight edges. It may be regarded as a portion of a cylinder of infinite radius, constituting one end of a series of curved diffracting surfaces of which the razor edge *E* is the other limit. The plate is adapted to be slightly rocked by tangent-screw mechanism so that its face may be adjusted very nearly parallel with the incident light.

When thus adjusted Lloyd's so-called "single-mirror interference fringes" are brilliantly shown, and the focal plane of the microscope may be moved through a wide range over the face of the mirror without disturbing the fringes in any way, proving that they have their origin on the surface of the mirror or plate, and not at its edges. The first one or two dark bands are very black and sharp, and the others show more and more color, until the fifth and beyond are all color. Only seven or eight fringes can be seen, and their spacing is sensibly uniform, as with ordinary interference fringes.

I shall now endeavor to show that these so-called "single-mirror interference fringes" are not due to interference of light reflected at grazing incidence with contiguous rays not reflected, as commonly supposed, but are superposed diffraction fringes like those already described.

Considered from this point of view, the origins of the many superposed fringe patterns all lie in the same plane and very nearly in the line of sight, and hence, owing to unequal spreading of the several patterns as already explained, some maxima begin to overlap some minima not far from the major edge of the composite pattern. Therefore few fringes are seen, and most of them are colored.

The extreme blackness of the dark bands forcibly suggests superposition of many minima. If the very small angle between the face of the mirror and the incident beam of light is gradually increased

by slowly turning the tangent screw, the fringes move closer together and lose their uniform spacing and most of their color, while the sharpest and blackest bands move further out in the pattern.

The width of the mirror, in the line of sight, may be reduced to 2 mm. without affecting the fringes in any respect; but with continued further reduction the fringes progressively lose their color, increase in number, and assume the characteristic spacing of diffraction fringes strongly reinforced by superposition of patterns, when the width is only a fraction of a millimeter.

These phenomena are beautifully shown by means of the device illustrated in diagram *P*. The plane glass mirror is here shown both in plan and elevation and enlarged to the scale of the razor blades *N* and *R*. It is in the form of a thin wedge about 12 mm. long and 3 mm. wide at the base, giving a triangular face. The line of sight is indicated by the dotted line.

Having adjusted the face of the mirror so as to produce the Lloyd fringes, and with the near edge of the mirror in the focal plane so as to prevent any edge effect, the mirror is very slowly moved on the microscope stage across the line of sight toward the point, without change of angle with the incident light. During this movement all the last described effects are developed. I may add that smoking the face of mirror *H* or *P* does not materially affect the brilliancy of the fringes.

In view of the facts cited it seems clear that the so-called "single-mirror interference fringes" of Lloyd are superposed diffraction fringes, and are not due to reflection. But to remove all doubt the device shown in diagram *R* was constructed.

This consists of 24 paper-thin razor blades clamped together and forming a bundle about 4 mm. thick. It is essential that all the edges be accurately brought to the same plane. But inasmuch as the edges of the blades are not perfectly straight, this condition can be realized only in two lines across the edge of the bundle. To effect this adjustment, the edges of the blades, very loosely clamped together, were allowed to rest by gravity against two parallel straight glass rods about half the length of the blades apart, and then cautiously clamped tight. Great care was taken to avoid injury to the

edges where they touched the rods, because it is only in these lines of contact, or very near them, that the effects to be described are produced. The glass rods were then removed and the bundle of blades was mounted and used in the same manner as the two-blade system *O* already described.

With this device, which precludes reflection, all the effects described in connection with the mirror *H* may be reproduced, differing only, and differing but little, in brilliancy. As only about half of all the edges (2 mm. across the edge of the bundle) are effective at any one time in producing visible fringes, it seems remarkable that the latter are so brilliant. But we must bear in mind that, say, twelve superposed fringe patterns will concentrate nearly all the light into the bright bands, leaving the dark bands nearly black; so that the contrasts should be nearly as strong as those produced by the far greater number of superposed patterns given by the mirror *H*.

The device *R* shows also something more of interest. Owing to the limited number of patterns formed, failure in registry may be seen at some points as division of a normal black band into two narrower dark lines which merge when the tangent screw is slightly turned, or the focal plane slightly moved; and this phenomenon may be shifted to different parts of the composite pattern by continuing either or both of these adjustments. Thus relative shifting of various fringe patterns, each more or less reinforced, is made obvious.

MATTER IN ITS ELECTRICALLY EXPLOSIVE STATE.

By FRANCIS E. NIPHER.

(*Read April 19, 1913.*)

In 1815 Singer published in the *Philosophical Magazine*[1] an account of experiments made in Holland by De Nelis, and repeated by him, which illustrated what he called the explosive effects of electricity. At that time the one-fluid theory was generally held by those familiar with electrical phenomena. It was, however, their belief that the electrical discharge came from the positive terminal.

Singer made use of a battery of jars having an external tin-foil area of 75 square feet. The positive terminal of this battery was separated from a terminal leading to a wire of lead having a diameter of 0.01 inch. This lead wire was within a small metal cylinder formed by boring a hole into a metal rod. One end of the wire was in contact with the bottom of the bore, the other being attached to a copper wire through which the discharge was sent to the lead wire. This leading in wire was surrounded by wax, and the lead wire was surrounded by oil. The lead wire was exploded by each discharge. The metal cylinder was stronger than any gun-barrel. It, however, was shattered by the explosive effects, the leading in wire was blown out and the liquid was sometimes thrown to the height of fifty feet when the metal cylinder did not burst.

At the present time it seems evident that, in these experiments, the lead wire was being suddenly drained of its negative corpuscles. What may properly be called a rarefaction wave was sent along the wire. When in this condition each atom of lead repels every other atom. The lead becomes explosive. There are heat effects involved also, which assist in the separation of the atoms, but which alone do not seem to be capable of accounting for the results.

It seemed to the present writer that it might be of interest to

[1] *Phil. Mag.*, Vol. 46, p. 161.

determine whether the explosive effects would be the same when the negative discharge was sent through the wire as when the positive terminal was used. In the former case a compression wave is sent through the corpuscular nebula within the wire. The repulsion effects are impressed upon the oil surrounding the wire. In the latter case the nature of the action seems to be essentially different, as has been pointed out above.

The wire was placed within a glass tube as shown in the adjoining figure. The internal diameter of various samples varied between one and two millimeters. The length of the tube was 10 cm. The ends of the tube were provided with copper leading-in wires fitting more or less closely the bore of the tube and to which the fine wire was attached, as shown in the adjoining figure. The walls of the tube were from one to two millimeters in thickness. The space within the tube around the wire was completely filled with coal-oil, all air being excluded. The ends of the tube and the leading-in

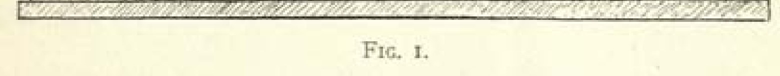

FIG. 1.

wires were sealed with sealing wax, which held the leading wires in place and secured these wires and the glass tube to supporting blocks of hard rubber.

The source of electricity was an influence machine, provided with a condenser consisting of twenty sheets of glass 66 cm. square, each plate having a tin-foil coating 30 cm. square. These plate condensers were connected in multiple, the tin-foil area being about 20 square feet on each side. A pivotally mounted ground contact could be connected to either terminal of the machine. By means of a similar contact rod either terminal could be connected with one of a set of discharge rods, provided with an adjustable spark gap between the knobs. The other discharge rod was connected with the water-pipe system of the building by means of two No. 8 copper wires in multiple. The apparatus shown in the figure was in this ground line. The ground for the machine was in the yard outside

of the building. The results were the same when the two grounds were thus independent as when they were united.

The wire to be exploded, contained within the glass tube of the figure, was a quarter ampere fuse wire, having a diameter of 0.115 mm. A small copper wire having a diameter of 0.105 mm. was also used with similar results.

A single discharge from either the positive or the negative side of the condenser caused the tube of glass to be shattered into fragments so minute that their impact upon the face of the observer when standing six or eight feet distant, produced no harmful effect. On several occasions, when the discharge came before it was expected, their impact upon the eyes was also harmless.

The small glass tube shown in the figure was enclosed in a larger tube having an internal diameter of about half an inch. This tube was also enclosed in a strip of cardboard. In this way the dust into which the inner tube was converted could be collected. It could only be recognized as glass on examination with a pocket lens.

The effect of the explosion upon the outer tube, the ends of which were open, was found to be in all cases more marked when the compression or negative discharge was sent through the wire than when the discharge rods and wire were connected with the positive terminal. In some cases the rarefaction wave would produce no apparent effect upon the outer tube, while the negative or compression wave would crack it or shatter it into three or four fragments.

In order to make comparative tests, the apparatus shown in the figure was constructed in pairs, the two tubes being cut from adjoining parts of the same glass tube. This was also done with the larger tubes which were placed between the supporting blocks and surrounded the small tube shown in the figure. In some cases two fuse wires or one fuse wire and one copper wire were placed in parallel within the tube. In this way the explosive effects were somewhat varied. In all cases the greater effects of the compression discharge were so marked that there appears to be no doubt of the result.

In order to compare the heat effects of an ordinary direct current, the wire was, by a switch connection, subjected to the current

from a separately excited 250-volt dynamo. The expansion effects then resulted in forcing the oil out through the sealing wax at the ends of the glass tube. No explosive effects were produced. The same experiment was repeated by switching the lead wire into a ground line attached to a city power plant, the impressed potential being 600 volts. The results were exactly the same as in the previous case, so far as explosive effects were concerned. The wire was fused and partly converted into a fine powder.

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THE ALLEGHENIAN DIVIDE, AND ITS INFLUENCE UPON THE FRESHWATER FAUNA.

(PLATES XII–XIV.)

ARNOLD E. ORTMANN, Ph.D., Sc.D.

(Read April 18, 1913.)

CONTENTS:

INTRODUCTION.

It is a well-known fact, noticed already by Rafinesque, in 1820 (Monogr. Coqu. Biv. et Fluv.), that the Appalachian Mountain system forms, for many freshwater animals, a sharp faunistic division line, which separates a fauna known as that of the *Interior Basin* from that of the *Atlantic Slope* (Mississippian and Atlantic Region

of Simpson, 1893, p. 354, and 1900a, p. 505, pl. 18). But it should be noted, from the beginning, that this holds good only for certain groups of animals, while in others no such differentiation is observed.

While this appears to be correct in a general way, investigations on the details of the relations of the two faunas on the eastern and the western side of the Alleghenies are very few. In fact, there are none whatever that have treated this question from a broader view-point. The most elementary requirement, the study of the actual distributional facts of freshwater animals, had been greatly neglected. From most of the more important rivers (Susquehanna, Potomac, Allegheny, Monongahela, Kanawha) hardly any observations were at hand, which would have permitted any definite opinion as to the general character of their faunas, and in the region of the head-waters of these, our previous knowledge was a blank.

For this reason, the present writer had first of all to undertake the task of obtaining reliable and complete data with regard to the fauna of the various streams running off the Alleghenian divide. In the course of these studies it became evident that the most important group of freshwater life is formed by the *Najades* or *Freshwater Mussels*. They offer two advantages: first they are very rich in species, the natural affinities of which are now rather clear; and second, they are forms which apparently possess no exceptional means of dispersal, that is to say, they are, as a rule, unable to cross from one drainage system into another over land (either actively or passively). This opinion of mine agrees with that held by Simpson (1900b), but is in sharp contrast to that expressed by Johnson (1905), who believes that "shells" or "mollusks" in general, and also especially Najades, have frequently been dispersed by birds, etc. Such cases may happen among the Najades, but they cannot be considered as the normal way, and Johnson's view rests upon very inadequate ideas about Najad-distribution, and chiefly the instances of apparent discontinuous distribution of species, which would favor the assumption of transport, are, without exception, founded upon defective facts. (It should be remembered that the chief means of dispersal of the Najades consists of transport in the larval state by fishes, on which the larvæ are attached; but this precludes the possibility of transport over land.)

Thus the present paper treats in the first line of the *Najades.* But there are other groups, which are important, yet they will be interesting only in so far as they confirm the results obtained from the Najades. These are certain freshwater *Gastropods,* and the crayfish-genus *Cambarus.* However, in the Gastropods we are handicapped by an insufficient knowledge of their mutual natural affinities; and in the Crayfishes the number of forms, which are to be considered, is rather small, so that it would be difficult to obtain general results from them alone.

In the present paper, the writer is going to pay attention only to that part of the Alleghenian divide which lies between the New York–Pennsylvania state line and the northern line of Tennessee (see Plate XII.). In the north we have a rather natural boundary: from about the New York state line northward the Glacial area begins, offering geological and physiographical features which are of rather recent age, and have created special conditions, which should be investigated separately. In the south, in the region of the headwaters of the Tennessee drainage, the conditions form the continuation of those farther north, but become here so complex that they deserve special study, to which additional, and much more extended investigations are necessary, involving the "Tennessee-Coosa problem."[1] I have considered the upper Tennessee only so

[1] This is the problem in which Johnson (1905) is especially interested. The old idea is (see chiefly Hayes, 1899) that the headwaters of the Tennessee once continued in the direction of the Coosa (*Appalachian River*), and that the present course of the Tennessee is due to a deflection in consequence of stream capture. Johnson believes (and also White, 1904) that the present course of the Tennessee is original, and I consider his physiographical evidence as perfectly sound and satisfactory. But since the Najades (and other freshwater groups) have been used to demonstrate the correctness of the assumption of the existence of the Appalachian River (see: Simpson, 1900b, p. 133, Adams, 1901, p. 846, and Ortmann, 1905, p. 130), we must take cognizance of this line of evidence, and dispose of it in some way. Johnson did this by dismissing it as not convincing, as not apt to demonstrate stream capture. However, as I have said, he is wrong in this, and I believe that the distribution of the Najades *does indicate stream capture in this region,* but in the opposite direction: the original fauna belonged to the old Tennessee (similar to the present in its course), and certain southern tributaries of it have been captured by the Coosa-Alabama system. This idea is already implied in Simpson's (1900b, p. 135) sentence: "it is probable that nearly all the

far as to ascertain the great contrast which exists between it and the river systems to the north of it. Thus my investigations cover, on the western side of the Alleghenies, the drainages of the Allegheny and Monongahela rivers (upper Ohio), of the Kanawha River, and in part only of the Big Sandy, Licking and Tennessee rivers (Clinch and Holston). On the eastern side, the systems of the Delaware, Susquehanna, Potomac, and of the upper James and Roanoke are included.

It is believed that the faunistic facts with regard to these rivers are reasonably complete and that my collections in them have furnished the knowledge, not only of what is present in them, but also of what is absent; under circumstances, this latter fact may even be more valuable than positive records.

Chapter I.

Statement of Distributional Facts in Najades.

The nomenclature of the Najades is that introduced by myself in some recent publications (chiefly Ortmann, 1912a, pp. 222 ff.). The lists give the number of distinguishable forms, no matter whether they are species or varieties. Unless otherwise stated, all information is founded upon the writer's personal experience, and the specimens from the various localities are preserved in the collections of the Carnegie Museum in Pittsburgh. The great mass of new distributional facts secured by the writer makes it imperative to give them in full. For this reason, the present chapter is somewhat lengthy and contains much that is uninteresting reading for those which are not specialists. But this is unavoidable.

A. WESTERN SIDE OF ALLEGHENIES.

I. The Upper Ohio Fauna in General.

First I give a complete list of species (or forms) found in the upper Ohio drainage, above Smith Ferry, Beaver Co., Pa., in the

Unionidæ of the Alabama River system have been derived from the Tennessee," and White (1904, p. 38) directly says that the upper course of the original Walden Gorge River (tributary to Tennessee) has been captured by Conasauga River (tributary to Oostanaula and Coosa Rivers).

Ohio, Allegheny, Monongahela Rivers, and their tributaries, excluding those found only in the Beaver or French Creek systems (Glacial Drift streams).[2]

List No. 1.

1. *Fusconaia subrotunda* (Lea)
2. *Fusconaia undata trigona* (Lea)
3. *Fusconaia undata rubiginosa* (Lea)
4. *Crenodonta plicata undulata* (Barn.)
5. *Quadrula pustulosa* (Lea)
6. *Quadrula lachrymosa* (Lea)
7. *Quadrula tuberculata* (Barn.)
8. *Quadrula metanevra* (Raf.)
9. *Quadrula cylindrica* (Say)
10. *Rotundaria tuberculata* (Raf.)
11. *Plethobasus cooperianus* (Lea)
12. *Plethobasus cyphus* (Raf.)
13. *Pleurobema obliquum* (Lamarck)
14. *Pleurobema obliquum pyramidatum* (Lea)
15. *Pleurobema obliquum coccineum* (Conr.)
16. *Pleurobema clava* (Lam.)
17. *Elliptio crassidens* (Lam.)
18. *Elliptio dilatatus* (Raf.)
19. *Symphynota compressa* Lea.
20. *Symphynota costata* (Raf.)
21. *Hemilastena ambigua* (Say)
22. *Anodonta grandis* Say
23. *Alasmidonta marginata* (Say)
24. *Strophitus edentulus* (Say)
25. *Ptychobranchus phaseolus* (Hildr.)
26. *Obliquaria reflexa* Raf.
27. *Cyprogenia irrorata* (Lea)

[2] Forms peculiar to Beaver or French Creek (or both) are: *Fusconaia subrotunda kirtlandiana* (Lea), *Symphynota complanata* (Barnes), *Anodonta imbecillis* Say, *Anodontoides ferussacianus* (Lea), *Carunculina parva* (Barnes).

Symphynota compressa Lea probably also falls in this category, but is also found in the uppermost Allegheny.

28. *Obovaria retusa* (Lam.)
29. *Obovaria circulus* (Lea)
30. *Obovaria circulus lens* (Lea)
31. *Obovaria ellipsis* (Lea)
32. *Nephronaias ligamentina* (Lam.)
33. *Amygdalonaias elegans* (Lea)
34. *Amygdalonaias donaciformis* (Lea)
35. *Plagiola depressa* (Raf.)
36. *Paraptera gracilis* (Barn.)
37. *Proptera alata* (Say)
38. *Eurynia fabalis* (Lea)
39. *Eurynia iris* (Lea)
40. *Eurynia recta* (Lam.)
41. *Lampsilis luteola* (Lam.)
42. *Lampsilis ovata* (Say)
43. *Lampsilis ovata ventricosa* (Barn.)
44. *Lampsilis multiradiata* (Lea)
45. *Lampsilis orbiculata* (Hildr.)
46. *Truncilla triquetra* (Raf.)
47. *Truncilla perplexa rangiana* (Lea)

It should be noted, that, of these, six forms (nos. 6, 11, 28, 31, 33, 34) have been found exclusively in the Ohio below Pittsburgh, while nine forms (nos. 3, 15, 16, 19, 25, 30, 38, 39, 47) have not been found there, but only above Pittsburgh, but they are found elsewhere in the Ohio drainage, so that they are not restricted to this region. No. 21 has been found only once, in the headwaters of the Monongahela, in West Fork River, in Lewis Co., W. Va. Thus there are *37 forms in the Ohio below Pittsburgh.*

II. Lower Allegheny and Monongahela Rivers.

There are, in the *Allegheny River* above Pittsburgh and below Franklin, Venango Co., Pa., the following Najades.

List No. 2.

1. *Fusconaia subrotunda* (Lea)
2. *Fusconaia undata rubiginosa* (Lea)

3. *Crenodonta plicata undulata* (Barn.)
4. *Quadrula pustulosa* (Lea)
5. *Quadrula tuberculata* (Barn.)
6. *Quadrula metanevra* (Raf.)
7. *Quadrula cylindrica* (Say)
8. *Rotundaria tuberculata* (Raf.)
9. *Plethobasus cyphyus* (Raf.)
10. *Pleurobema obliquum* (Lam.)
11. *Pleurobema obliquum pyramidatum* (Lea)
12. *Pleurobema obliquum coccineum* (Conr.)
13. *Pleurobema clava* (Lam.)
14. *Elliptio crassidens* (Lam.)
15. *Elliptio dilatatus* (Raf.)
16. *Symphynota costata* (Raf.)
17. *Alasmidonta marginata* (Say)
18. *Strophitus edentulus* (Say)
19. *Cyprogenia irrorata* (Lea)
20. *Obovaria circulus lens* (Lea)
21. *Nephronaias ligamentina* (Lam.)
22. *Plagiola depressa* (Raf.)
23. *Paraptera gracilis* (Barn.)
24. *Proptera alata* (Say)
25. *Eurynia recta* (Lam.)
26. *Lampsilis luteola* (Lam.)
27. *Lampsilis ovata* (Say)
28. *Lampsilis ovata ventricosa* (Barn.)
29. *Lampsilis multiradiata* (Lea)
30. *Lampsilis orbiculata* (Hildr.)
31. *Truncilla triquetra* (Raf.)
32. *Truncilla perplexa rangiana* (Lea)

Aside from the six species found only below Pittsburgh, the following nine of list no. 1 are missing here: nos. 2, 19, 21, 22, 25, 26, 29, 38, 39.

A very similar fauna goes up the *Monongahela River*. Unfortunately, this fauna is now destroyed, and our knowledge of it rests upon a collection in the Carnegie Museum made before 1897 by

G. A. Ehrmann in the vicinity of Charleroi, Washington Co., Pa. (and a few scattered additional records secured by others). The following is the list of these.

List No. 3.

1. *Fusconaia subrotunda* (Lea)
2. *Fusconaia undata trigona* (Lea)
3. *Fusconaia undata rubiginosa* (Lea)
4. *Quadrula pustulosa* (Lea)
5. *Quadrula tuberculata* (Barn.)
6. *Quadrula metanevra* (Raf.)
7. *Quadrula cylindrica* (Say)
8. *Plethobasus cyphyus* (Raf.)
9. *Pleurobema obliquum* (Lam.)
10. *Pleurobema obliquum pyramidatum* (Lea)
11. *Elliptio crassidens* (Lam.)
12. *Elliptio dilatatus* (Raf.)
13. *Symphynota costata* (Raf.)
14. *Anodonta grandis* Say
15. *Strophitus edentulus* (Say)
16. *Ptychobranchus phaseolus* (Hildr.)
17. *Obliquaria reflexa* Raf.
18. *Cyprogenia irrorata* (Lea)
19. *Obovaria circulus* (Lea)
20. *Obovaria circulus lens* (Lea)
21. *Nephronaias ligamentina* (Lam.)
22. *Plagiola depressa* (Raf.)
23. *Paraptera gracilis* (Barn.)
24. *Proptera alata* (Say)
25. *Eurynia recta* (Lam.)
26. *Lampsilis luteola* (Lam.)
27. *Lampsilis ovata ventricosa* (Barn.)
28. *Lampsilis orbiculata* (Hildr.)

The following species have not been found here, but were probably present in this region, since they exist both below and above:

29. *Crenodonta plicata undulata* (Barn.)
30. *Rotundaria tuberculata* (Raf.)
31. *Alasmidonta marginata* (Say)
32. *Lampsilis multiradiata* (Lea)
33. *Truncilla triquetra* (Raf.)

Comparing these two lists (nos. 2 and 3), we see that they are practically identical: 23 forms are in either list, to which probably five others should be added, which should be expected in this part of the Monongahela. Thus there would be 28 forms common to these rivers.

Even those species, which are peculiar to only one of these rivers, might exist or might have existed in the other. In a general way, those species found in the Monongahela, and not in the Allegheny, are preëminently big-river-forms (for instance *Fusc. undata trigona, Obliquaria reflexa, Obovaria circulus*), while, vice versa, those of the Allegheny are small-river-forms (*Pleurobema obliquum coccineum, Pleurobema clava, Truncilla perplexa rangiana*). This is in keeping with the general character of these rivers; the Monongahela is, although not appreciably larger, more quiet and steady, with finer bottom (gravel, sand), while the Allegheny is rather rough, with coarser gravel and rocks.

One thing is very evident: that the Ohio fauna extends into both rivers above Pittsburgh, but somewhat depauperated, decreasing from 37 to about 30 Najad-forms.

III. The Upper Allegheny and its Tributaries.

Going up the Allegheny River, we meet first a section, which is utterly polluted (from northern Armstrong Co., to Oil City, Venango Co.). But above Oil City the river is in good condition, up to Warren Co., and the New York state line. In this stretch (Venango, Forest, and Warren Cos.), the following Najades have been collected by the writer:

List No. 4.

1. *Crenodonta plicata undulata* (Barn.)
2. *Rotundaria tuberculata* (Raf.)

3. *Pleurobema obliquum coccineum* (Conr.)
4. *Pleurobema clava* (Lam.)
5. *Elliptio dilatatus* (Raf.)
6. *Symphynota costata* (Raf.)
7. *Alasmidonta marginata* (Say)
8. *Strophitus edentulus* (Say)
9. *Ptychobranchus phaseolus* (Hildr.)
10. *Nephronaias ligamentina* (Lam.)
11. *Eurynia fabalis* (Lea)
12. *Eurynia recta* (Lam.)
13. *Lampsilis ovata* (Say)
14. *Lampsilis ovata ventricosa* (Barn.)
15. *Lampsilis multiradiata* (Lea)
16. *Truncilla perplexa rangiana* (Lea)

To these should be added, as found in tributaries of the Allegheny in Warren Co.:

17. *Symphynota compressa* Lea
18. *Anodonta grandis* Say
19. *Lampsilis luteola* (Lam.)

Compared with the lower Allegheny (list no. 2), the number of species has been reduced by more than a third, but for those which have disappeared a few others have turned up, namely, nos. 9, 11, 17 and 18. Of these, *Symphynota compressa* (no. 17) is a peculiar form restricted to the tributaries of the upper Allegheny (and also in French Creek and Beaver River drainage, see above, p. 291, footnote 2). The others are species which generally prefer small streams and avoid larger rivers.

Above Warren Co., Pa., the Allegheny River flows in New York state, and we have only a few records from this section (Marshall, 1895). But then we reach Pennsylvania again in McKean Co. Here I secured a number of species in the Allegheny River, and received others from Dennis Dally, and P. E. Nordgren made a collection in Potato Creek. Here is the list of these.

List No. 5.

(Those marked * are from the *Allegheny,* those marked † from *Potato Creek.*)

*1. *Pleurobema obliquum coccineum* (Conr.)
*†2. *Elliptio dilatatus* (Raf.)
†3. *Symphynota compressa* Lea
*†4. *Symphynota costata* (Raf.)
*5. *Alasmidonta marginata* (Say)
†6. *Strophitus edentulus* (Say)
*†7. *Lampsilis luteola* (Lam.)
*8. *Lampsilis ovata ventricosa* (Barn.)

The number of forms again has been greatly reduced in comparison with list no. 4. All species found here are also found farther below, and thus this fauna is simply depauperated.

I collected also in the uppermost Allegheny above Coudersport, Potter Co., but here this is a mere run, and has no Najades. (Immediately below Coudersport it is polluted.)

We come now to the eastern tributaries of the Allegheny River, running down from the divide in a general east–west direction. They are (from north to south): *Clarion River, Red Bank River, Mahoning Creek, Crooked Creek,* and *Kiskiminetas River.* The first two are entirely polluted, and no shells are known from them. The same is true for Mahoning Creek, from Punxsutawney down. But in northern Indiana Co. there is a tributary of the latter, *Little Mahoning Creek,* where I collected the following shells:

List No. 6.

1. *Pleurobema obliquum coccineum* (Conr.)
2. *Elliptio dilatatus* (Raf.)
3. *Symphynota costata* (Raf.)
4. *Alasmidonta marginata* (Say)
5. *Strophitus edentulus* (Say)
6. *Ptychobranchus phaseolus* (Hildr.)
7. *Lampsilis luteola* (Lam.)
8. *Lampsilis ovata ventricosa* (Barn.)

The similarity of this fauna to that of the uppermost Allegheny is evident. Eight forms are in either list, seven of which are found in both.

Crooked Creek has its fauna fully preserved. I collected in both the lower and upper part. In the lower part, in Armstrong Co., near its confluence with the Allegheny, the following are found.

List No. 7a.

1. *Fusconaia undata rubiginosa* (Lea)
2. *Crenodonta plicata undulata* (Barn.)
3. *Pleurobema obliquum coccineum* (Conr.)
4. *Elliptio dilatatus* (Raf.)
5. *Symphynota costata* (Raf.)
6. *Anodonta grandis* Say
7. *Alasmidonta marginata* (Say)
8. *Strophitus edentulus* (Say)
9. *Obovaria circulus lens* (Lea)
10. *Nephronaias ligamentina* (Lam.)
11. *Eurynia fabalis* (Lea)
12. *Eurynia iris* (Lea)
13. *Eurynia recta* (Lam.)
14. *Lampsilis luteola* (Lam.)
15. *Lampsilis ovata ventricosa* (Barn.)
16. *Lampsilis multiradiata* (Lea)
17. *Truncilla triquetra* Raf.

This is a depauperated lower Allegheny fauna, with the addition of a few species (nos. 6, 11, 12) which are characteristic for smaller streams.

In the upper part of Crooked Creek, in Indiana Co., there are:

List No. 7b.

1. *Fusconaia undata rubiginosa* (Lea)
2. *Symphynota costata* (Raf.)
3. *Anodonta grandis* Say
4. *Strophitus edentulus* (Say)

5. *Obovaria circulus lens* (Lea)
6. *Lampsilis luteola* (Lam.)

This part of the creek is a very small stream. Of the six species found here, three are also in the uppermost Allegheny and in Little Mahoning, while three (nos. 1, 3, 5) are absent in them. *Anodonta grandis* is a small-creek-form elsewhere, but *Fusconaia undata rubiginosa* and *Obovaria circulus lens* are peculiar to this creek, and although they are also small-creek-forms, they are not known to advance so far up toward the divide in other rivers. Of course, we should bear in mind that other tributaries of the Allegheny in this section, the fauna of which has been destroyed, might have contained these species.

The full and typical *Kiskiminetas-Conemaugh* fauna is irreparably lost to us on account of pollution of the waters. However, a few remnants have been preserved. Nothing is known from the Kiskiminetas proper. In the *Conemaugh River* at New Florence, Westmoreland Co., I found the dead shells of the following forms:

1. *Pleurobema obliquum coccineum* (Conr.)
2. *Pleurobema clava* (Lam.)
3. *Elliptio dilatatus* (Raf.)
4. *Ptychobranchus phaseolus* (Hildr.)
5. *Nephronaias ligamentina* (Lam.)
6. *Eurynia recta* (Lam.)
7. *Lampsilis ovata ventricosa* (Barn.)
8. *Lampsilis multiradiata* (Lea)

These are all found in the Allegheny above Oil City, but it is hardly probable that this list contains more than half of the species originally present in the Conemaugh.

From small tributaries in Westmoreland and Indiana Cos., I was able to secure four species:

Elliptio dilatatus (Raf.)—Yellow Creek, Indiana Co.
Symphynota costata (Raf.)—Two Lick Creek, Indiana Co.
Anodonta grandis Say—Beaver Run, Westmoreland Co.
Strophitus edentulus (Say)—Yellow Creek and Blacklegs Creek, Indiana Co., and Beaver Run, Westmoreland Co.

Also this fauna is fragmentary, since these streams are partially polluted. But there are two tributaries of the Kiskiminetas system, in the mountains, between Chestnut Ridge, Laurel Hill Ridge, and Allegheny Front, which have furnished what appears as complete faunas. *Loyalhanna River,* near Ligonier, Westmoreland Co., contains:

List No. 8.

1. *Pleurobema obliquum coccineum* (Conr.)
2. *Pleurobema clava* (Lam.)
3. *Elliptio dilatatus* (Raf.)
4. *Symphynota costata* (Raf.)
5. *Alasmidonta marginata* (Say)
6. *Strophitus edentulus* (Say)
7. *Ptychobranchus phaseolus* (Hildr.)
8. *Lampsilis ovata ventricosa* (Barn.)
9. *Lampsilis multiradiata* (Lea)

Also *Anodonta grandis* Say should be mentioned, but this has been found only in ponds cut off from the river. Of *Nephronaias ligamentina* (Lam.) a single individual has been found many years ago, but recent investigations have failed to bring it to light again.

Seven of these species have occurred in the other lists of the tributaries of the Allegheny, while two are new (nos. 2 and 9).

In *Quemahoning Creek,* in Somerset Co., I collected:

List No. 9.

1. *Elliptio dilatatus* (Raf.)
2. *Symphynota costata* (Raf.)
3. *Alasmidonta marginata* (Say)
4. *Strophitus edentulus* (Say)
5. *Ptychobranchus phaseolus* (Hildr.)
6. *Lampsilis ovata ventricosa* (Barn.)
7. *Lampsilis multiradiata* (Lea)

All these are also found in the Loyalhanna, but two of the latter (nos. 1 and 2) are lacking.

The streams belonging to the Allegheny, discussed so far, form

a unit, as will become evident by comparison with the next group (upper Monongahela drainage). This is the most easterly advanced part of the Allegheny drainage. For this reason it will be advantageous to give the full list of all species which advance here farthest toward the Alleghenian divide.

Combined Lists: 6, 7b, 8, 9.

1. *Fusconaia undata rubiginosa* (Lea)
2. *Pleurobema obliquum coccineum* (Conr.)
3. *Pleurobema clava* (Lam.)
4. *Elliptio dilatatus* (Raf.)
5. *Symphynota compressa* Lea
6. *Symphynota costata* (Raf.)
7. *Anodonta grandis* Say
8. *Alasmidonta marginata* (Say)
9. *Strophitus edentulus* (Say)
10. *Ptychobranchus phaseolus* (Hildr.)
11. *Obovaria circulus lens* (Lea)
12. *Lampsilis luteola* (Lam.)
13. *Lampsilis ovata ventricosa* (Barn.)
14. *Lampsilis multiradiata* (Lea)

This is a comparatively rich fauna. Although not all of these 14 species are found in every one of these streams, the average number is about 7 or 8. Some of the species (*Symphynota costata, Strophitus edentulus*) are found in all of these creeks, and five species are in most of them (*Pleurobema obliquum coccineum, Elliptio dilatatus, Alasmidonta marginata, Ptychobranchus phaseolus, Lampsilis ovata ventricosa*).

Looking over the Allegheny River fauna, we see that the Ohio fauna, well and richly represented in the Ohio below Pittsburgh by 37 forms, depauperates in the Allegheny. Although a few species are added toward the headwaters, the general tendency is that one species after the other disappears in the upstream direction. But one feature of this should be emphasized: the decrease in the number of forms is *gradual,* no sudden deterioration of the fauna being

observed at any point. In the uppermost headwaters there is yet a comparatively rich fauna of together 14 species.

We shall see that in other parts of the western drainage this condition is not found, and our rather detailed account of the Allegheny fauna has been given with the chief purpose of bringing out the above fact.

IV. Monongahela River and Tributaries.

We have seen above (list no. 3) that the Monongahela just above Pittsburgh had surely 28 species, but possibly 33. Farther up no Najades are known and the fauna is destroyed, for the water is everywhere badly polluted. But above Clarksburg, Harrison Co., W. Va., conditions are good again in *West Fork River*. This is a Plateau stream, not rough, but rather sluggish, and the proper environment for shell-life seems to be present. The Carnegie Museum possesses material collected by the writer at Lynch Mines, Harrison Co., at Lightburn and Weston, Lewis Co., and some additional forms collected by J. P. Graham at West Milford, Harrison Co., W. Va. This gives us a good, and, as I believe, a rather complete idea of this fauna.

In the following list those forms found at the uppermost point in this river (Weston) are marked with a *. (None is peculiar to this locality.)

List No. 10.

1. *Fusconaia subrotunda* (Lea)
*2. *Crenodonta plicata undulata* (Barn.)
3. *Quadrula tuberculata* (Barn.)
4. *Quadrula metanevra wardi* (Lea)
5. *Quadrula cylindrica* (Say)
6. *Rotundaria tuberculata* (Raf.)
*7. *Pleurobema obliquum coccineum* (Conr.)
*8. *Pleurobema clava* (Lam.)
*9. *Elliptio dilatatus* (Raf.)
*10. *Symphynota costata* (Raf.)
11. *Hemilastena ambigua* (Say)

*12. *Anodonta grandis* Say
*13. *Alasmidonta marginata* (Say)
*14. *Strophitus edentulus* (Say)
15. *Ptychobranchus phaseolus* (Hildr.)
*16. *Obovaria circulus lens* (Lea)
*17. *Eurynia fabalis* (Lea)
*18. *Eurynia iris* (Lea)
*19. *Lampsilis luteola* (Lam.)
*20. *Lampsilis ovata ventricosa* (Barn.)
*21. *Lampsilis multiradiata* (Lea)
22. *Truncilla triquetra* Raf.
23. *Truncilla perplexa rangiana* (Lea)

This is a fauna very similar to that farther below, but somewhat depauperated. It is remarkable that this fauna goes far up, and that there are yet 14 species at the uppermost locality (Weston), where the river is merely a creek. Also here the rule holds good, that the typical Ohio fauna decreases in richness in an upstream direction, and that this decrease is gradual, not sudden.

In sharp contrast to this are the eastern tributaries of the Monongahela, which come down from the mountains. The first of them is the *Youghiogheny River*. The fauna of the lower parts of this river is entirely lost on account of pollution. Between Connelsville and Confluence, Fayette Co., Pa., the river runs through a canyon, is very rough, forming falls (largest at Ohiopyle). Above Confluence it is less rapid, and flows in a broad valley, offering conditions favorable to Najades; but only a single species is found here:

Strophitus edentulus (Say).

The next of the mountain streams is *Cheat River*. Also this river runs through a long canyon, and above this canyon there are no Najades in it.[3] But below the canyon the fauna is rich. In the following list, the species marked * are found also at Mont Chateau,

[3] I collected above Parsons, Tucker Co., W. Va., in *Shavers Fork*. Below Parsons the river is badly polluted, and also *Dry Fork* is polluted through *Blackwater River*. I have been told that there used to be some shells in the Cheat, below Parsons, but we have no means of ascertaining what species they were.

W. Va., immediately below the canyon, the others are from Cheat Haven in Pennsylvania, about eight miles farther below.

List No. 11.

1. *Fusconaia subrotunda* (Lea)
2. *Crenodonta plicata undulata* (Barn.)
3. *Quadrula pustulosa* (Lea)
4. *Rotundaria tuberculata* (Raf.)
5. *Pleurobema clava* (Lam.)
*6. *Elliptio dilatatus* (Raf.)
*7. *Symphynota costata* (Raf.)
*8. *Alasmidonta marginata* (Say)
*9. *Strophitus edentulus* (Say)
*10. *Ptychobranchus phaseolus* (Hildr.)
11. *Nephronaias ligamentina* (Lam.)
12. *Eurynia iris* (Lea)
*13. *Eurynia recta* (Lam.)
*14. *Lampsilis ovata ventricosa* (Barn.)
*15. *Lampsilis multiradiata* (Lea)

The eight species found near Mont Chateau are not in the main channel of the river, but in small side branches, which are more or less protected. In the main channel the bottom consists of large boulders and rocks, not firmly packed, but loose and easily movable, chiefly at flood stage. Moving and shifting bottom prevents permanent settlement of Najades. At Cheat Haven conditions are more favorable, and here we have a rich fauna, agreeing well with that of the lower Monongahela, but of course somewhat depauperated corresponding to the smaller size of the river.

Tygart Valley River, which joins West Fork River at Fairmont, to form the Monongahela, has the same character as the Cheat. There is a more slowly running upper part, above Elkins, Randolph Co., W. Va., a rather long canyon, down to Grafton, and a less rough portion below this. In the canyon a tributary flows into it, *Buckhannon River,* which again is running more slowly in its upper part.

In the lower Tygart, the fauna has been destroyed by pollution. The upper part, above Elkins, contains only two species:

Symphynota costata (Raf.)
Strophitus edentulus (Say)

The upper part of the Buckhannon drainage has one species:

Strophitus edentulus (Say)

I found this not in the river itself, which is dammed and has slack water, but in a small tributary, *French Creek,* at Hampton, Upshur Co., W. Va.

Thus, in these mountain streams tributary to the upper Monongahela, we meet with conditions entirely different from those in the upper Allegheny and its tributaries: the rich Ohio fauna, only slightly depauperated, goes up to a certain point, up to the lower end of a canyon, which represents an extremely rough part of these rivers. This is best observed in the case of the Cheat (list no. 11), while in the others pollution has destroyed the original conditions. But we may easily imagine what these were when we look at the fauna of the plateau stream, West Fork River (see list 10). At the lower end of the canyon the fauna suddenly stops, and above the canyon, in the high valleys, where the rivers are more quiet, very few species, one or two, are found, if such are present at all. It should be noted that one species, *Strophitus edentulus,* is found in all three rivers, which have shells, but that *Symphynota costata* is only in the Tygart.

Thus the canyon apparently forms here a natural barrier.

V. Fauna of the Kanawha River.

Farther to the south we have the Kanawha drainage in West Virginia. The fauna of the Kanawha itself is unknown, for this river is much polluted, and has been transformed into a series of pools by dams, conditions unfavorable for Najad-life.

However, there are two tributaries in the plateau-region, which contain shells. The first is *Elk River.* Here I collected repeatedly and was able to secure the following species. Those marked * are from the uppermost station, at Sutton, Braxton Co., W. Va.

List No. 12.

*1. *Fusconaia subrotunda leucogona* Ort.
*2. *Fusconaia undata trigona* (Lea)
*3. *Crenodonta plicata undulata* (Barn.)
4. *Quadrula pustulosa* (Lea)
*5. *Quadrula tuberculata* (Barn.)
6. *Rotundaria tuberculata* (Raf.)
*7. *Pleurobema clava* (Lam.)
8. *Elliptio crassidens* (Lam.)
*9. *Elliptio dilatatus* (Raf.)
*10. *Symphynota costata* (Raf.)
11. *Alasmidonta marginata* (Say)
*12. *Strophitus edentulus* (Say)
*13. *Ptychobranchus phaseolus* (Hildr.)
*14. *Obovaria circulus* (Lea)
15. *Nephronaias ligamentina* (Lam.)
*16. *Proptera alata* (Say)
17. *Eurynia fabalis* (Lea)
*18. *Eurynia iris* (Lea)
19. *Eurynia recta* (Lam.)
20. *Lampsilis ovata* (Say)
*21. *Lampsilis ovata ventricosa* (Barn.)
*22. *Lampsilis multiradiata* (Lea)

This fauna is of typical upper Ohio character (compare lists 2 and 3). With one exception (*Fusconaia subrotunda leucogona*) every form is also found in western Pennsylvania, and this one is only the local representative of *Fusconaia subrotunda*. Yet this fauna has a somewhat peculiar "facies" in so far as it contains several forms, which elsewhere prefer larger rivers (*Fusconaia undata trigona, Elliptio crassidens, Obovaria circulus, Proptera alata*).

In addition I collected some shells in *Coal River*, at Sproul, Kanawha Co., W. Va.

1. *Fusconaia undata rubiginosa* (Lea)
2. *Crenodonta plicata undulata* (Barn.)

3. *Strophitus edentulus* (Say)
4. *Obovaria circulus lens* (Lea)
5. *Lampsilis luteola* (Lam.)
6. *Lampsilis multiradiata* (Lea)

And the Carnegie Museum possesses, from *Little Coal River*, from the Hartman collection:

7. *Quadrula pustulosa* (Lea)
8. *Quadrula metanevra wardi* (Lea)
9. *Pleurobema obliquum coccineum* (Conr.)

This would add 5 forms (nos. 1, 4, 5, 8, 9), so that 27 forms are known from the lower Kanawha drainage, which are practically all typical upper Ohio forms.

Going up the Kanawha, we find that this river, as *New River*, comes through a canyon out of the mountains. This canyon is extremely rough, containing several falls (Kanawha falls at lower end of canyon, and New Richmond falls, eight miles below Hinton. Good photographs of New River scenery have been published by Campbell and Mendenhall, 1896). In the region of Hinton, Summers Co., W. Va., the river is somewhat less rough. Here I collected, at the confluence of *New River* and *Greenbrier River*, the following species:

List No. 13.

1. *Quadrula tuberculata* (Barn.)
2. *Rotundaria tuberculata* (Raf.)
3. *Elliptio dilatatus* (Raf.)
4. *Symphynota tappaniana* (Lea)

To these, probably, *Alasmidonta marginata* (Say) should be added, for it is found farther up in the New River drainage, and thus we would have five species here, four of which are found in the lower Kanawha drainage, while one (*Symphynota tappaniana*) is entirely new, and found nowhere else in the whole upper Ohio drainage. In fact, this is a species known hitherto only from the Atlantic watershed.

Farther up I collected in the *Greenbrier River* at Ronceverte, Greenbrier Co., W. Va.; in *New River* at Pearisburg, Giles Co., Va.;

and in *Reed Creek*, Wytheville, Wythe Co., Va. Three species only are present here:

List No. 14.

1. *Elliptio dilatatus* (Raf.)
2. *Symphynota tappaniana* (Lea)
3. *Alasmidonta marginata* (Say)

At Pearisburg I did not find no. 3, but at the other localities all three were present. In addition, *Elliptio dilatatus* has been reported by Call ('85, p. 30) from *Bluestone River* (tributary to New River, emptying into it just above Hinton).[4]

These conditions correspond closely to what we have observed in the case of the mountain streams tributary to the Monongahela. There is a rough part in the river in the shape of a canyon. Below the canyon the fauna is rich, above it is extremely poor. In the present case two species (*Quadrula tuberculata* and *Rotundaria tuberculata*) have gone up through the lower part of the canyon, but they were unable to go farther, and the uppermost parts of the New River system, where conditions undoubtedly are favorable for Najades, contain only three species, two of which belong to the Ohio fauna, *while the third is a complete stranger.* With the exception of this case, which will be further discussed below, the whole Kanawha fauna, including that of New River, is undistinguishable from the general upper Ohio fauna. But it should be noted that the species found in the headwaters of the Kanawha are different from those found in the headwaters of the mountain tributaries of the Monongahela.

VI. Big Sandy and Licking Rivers.

South of the headwaters of New River, in the Greater Allegheny Valley, we strike the headwaters of the Tennessee drainage, Holston,

[4] Bluestone River is now badly polluted. I have seen it in its upper part, at Rock, Mercer Co., W. Va. Call (*ibid.*, p. 55) already gives *Rotundaria tuberculata* (as *Unio verrucosus* Barn.) from New River, *Virginia*: but according to my investigations, this is only in the New River in *West Virginia* (at Hinton). Call also says Bluestone River, Virginia, but only the extreme headwaters are in Virginia, the rest in West Virginia.

Clinch and Powell Rivers. However, to the west of these, on the Allegheny Plateau, there are other rivers, tributary to the Ohio, the fauna of which was hitherto entirely unknown. Since a quite different fauna turns up in the Tennessee, it would be surely interesting to know something about these intermediate western rivers, and for this reason I made several trips into this region, and was able to collect the following data, first for the *Levisa Fork of Big Sandy River,* at Prestonsburg, Floyd Co., Ky.

1. *Fusconaia subrotunda* (Lea)
2. *Crenodonta plicata undulata* (Barn.)
3. *Quadrula pustulosa* (Lea)
4. *Quadrula tuberculata* (Barn.)
5. *Elliptio crassidens* (Lam.)
6. *Symphynota costata* (Raf.)
7. *Obovaria circulus lens* (Lea)
8. *Nephronaias ligamentina* (Lam.)
9. *Amygdalonaias elegans* (Lea)
10. *Proptera alata* (Say)
11. *Eurynia recta* (Lam.)
12. *Lampsilis ovata ventricosa* (Barn.)

In the *Licking River,* at Farmer, Rowan Co., Ky., I found:

1. *Crenodonta plicata undulata* (Barn.)
2. *Quadrula pustulosa* (Lea)
3. *Quadrula tuberculata* (Barn.)
4. *Pleurobema obliquum coccineum* (Conr.)
5. *Elliptio dilatatus* (Raf.)
6. *Symphynota costata* (Raf.)
7. *Anodonta grandis* Say
8. *Strophitus edentulus* (Say)
9. *Ptychobranchus phaseolus* (Hildr.)
10. *Obovaria circulus lens* (Lea)
11. *Nephronaias ligamentina* (Lam.)
12. *Proptera alata* (Say)
13. *Lampsilis luteola* (Lam.)
14. *Lampsilis ovata ventricosa* (Barn.)

In a tributary of the Licking, *Fleming Creek* at Pleasant Valley, Nicholas Co., Ky., I found, aside from *Anodonta grandis* and *Lampsilis luteola:*

15. *Anodontoides ferussacianus* (Lea)

Although these two lists give by no means the complete faunas of these rivers, they show clearly that they are practically identical with the upper Ohio drainage in West Virginia and western Pennsylvania. All these species have occurred in our previous lists, with one exception, the very last one, *Anodontoides ferussacianus.* This is a western and northern species. Of the characteristic Tennessee (and Cumberland) drainage fauna not a trace is seen in these rivers.

It is unknown at present whether there is a point in the upper parts of these rivers, where the fauna stops suddenly in an upstream direction. My chief object in introducing here the faunas of these rivers is to show that they cannot be separated from the general Ohio fauna.

VII. Fauna of Upper Tennessee River.

We come now to the Tennessee River. It is well known that this system contains an extremely rich fauna, with a large number of peculiar types. It is not my object to go into detail here, and I only want to bring out the contrast of this fauna to that of the upper Ohio in general, and especially to that of upper New River. With this in view, I collected (September, 1912) in the uppermost parts of *Holston* and *Clinch Rivers* in Virginia. Of course, my collections are by no means complete, as is clearly shown by a comparison with the list published for Holston River by Lewis ('71), which, however, needs revision. But what I have found is sufficient for the present purpose.

List No. 16.

Middle and *North Fork Holston,* in Smyth Co.
(Those marked * only in Middle Fork.)

1. *Fusconaia* sp.?
2. *Pleurobema* (possibly 2 species)
3. *Pleurobema fassinans* (Lea)

4. *Symphynota costata* (Raf.)
5. *Alasmidonta minor* (Lea)
6. *Alasmidonta fabula* (Lea)
7. *Alasmidonta marginata* (Say)
8. *Strophitus edentulus* (Say)
9. *Ptychobranchus subtentus* (Say)
10. *Nephronaias perdix* (Lea)
*11. *Nephronaias copei* (Lea)
12. *Medionidus conradicus* (Lea)
13. *Eurynia nebulosa* (Conr.)
*14. *Eurynia dispansa* (Lea)
15. *Eurynia vanuxemensis* (Lea)
16. *Lampsilis ovata ventricosa* (Barn.)
17. *Lampsilis multiradiata* (Lea)

Clinch, in Tazewell Co.

1. *Fusconaia bursa-pastoris* (Wright)
2. *Fusconaia* sp.?
3. *Quadrula cylindrica strigillata* (Wright)
4. *Pleurobema* (probably 2 species)
5. *Elliptio dilatatus* (Raf.)
6. *Symphynota holstonia* (Lea)
7. *Symphynota costata* (Raf.)
8. *Alasmidonta minor* (Lea)
9. *Alasmidonta marginata* (Say)
10. *Strophitus edentulus* (Say)
11. *Ptychobranchus subtentus* (Say)
12. *Medionidus conradicus* (Lea)
13. *Eurynia perpurpurea* (Lea)
14. *Eurynia nebulosa* (Conr.)
15. *Eurynia planicostata* (Lea)
16. *Lampsilis ovata ventricosa* (Barn.)
17. *Lampsilis multiradiata* (Lea)
18. *Truncilla haysiana* (Lea)
19. *Truncilla capsaeformis* (Lea)

These are altogether about 26 species, of which only 6 have occurred in our previous lists (*Elliptio dilatatus, Symphynota cos-*

tata, Alasmidonta marginata, Strophitus edentulus, Lampsilis ovata ventricosa, Lampsilis multiradiata). All others (about 20) are not found in the upper Ohio drainage; some have representative forms there (*Fusconaia bursa-pastoris, Quadrula cylindrica strigillata, Eurynia nebulosa, Truncilla capsaeformis*); but others are types, which are not at all represented there (*Pleurobema fassinans, Alasmidonta minor* and *fabula*, the genus *Medionidus, Eurynia perpurpurea* and *vanuxemensis, Truncilla haysiana* are the most important ones).

It should be noted especially that the New River species, *Elliptio dilatatus* and *Alasmidonta marginata*, which are found in the Tennessee drainage, are not represented by identical forms. *Elliptio dilatatus* of upper New River is a dwarf race, while the Clinch type is large and normal. The Clinch and Holston type of *Alasmidonta marginata* is peculiar by its extremely bright color markings.

The contrast between these rivers is thus clearly established, and becomes even more striking, when we consider the fact that in general physiographic characters these rivers are very similar to each other, and further, that the Holston and Clinch, where I collected in them, are much smaller, mere creeks, compared, for instance, with New River at Pearisburg.

Summary of Facts Concerning the Western Fauna.

To express it in a few words, the chief features of the western fauna are: a *uniform fauna* goes from Licking River up through the whole upper Ohio drainage into the headwaters of the Allegheny, but in the mountain streams tributary to the Monongahela and Kanawha *a sudden depauperation is observed and farther above very few species are present.* The fauna of the upper Tennessee is related to the Ohio fauna, but has *many peculiar elements.* As a whole, the Ohio fauna is to be regarded as a somewhat depauperated Tennessee fauna; this is not so evident from the lists given above, but is a well-known fact, for which we do not need to furnish here particular proof.

B. Atlantic Side.

Besides the writer's own investigations, the following publications have been used for compilation of the faunistic lists:

For Delaware, Susquehanna, and Potomac rivers: Gabb, 1861; Hartman and Michener, 1874; Pilsbry, 1894; Schick, 1895; Caffrey, 1911.

For James River: Conrad, 1846.

Since the Atlantic side does not form a single drainage system, but consists of a number of rivers running independently to the sea, we must discuss these rivers separately.

I. The Fauna of the Delaware River.

This is the most northern system in the region discussed here. The following Najades are known to exist here:

List No. 17.

1. *Margaritana margaritifera* (L.)
2. *Elliptio complanatus* (Dillw.)
3. *Elliptio fisherianus* (Lea)
4. *Symphynota tappaniana* (Lea)
5. *Anodonta cataracta* Say
6. *Anodonta implicata* Say
7. *Alasmidonta heterodon* (Lea)
8. *Alasmidonta undulata* (Say)
9. *Alasmidonta varicosa* (Lam.)
10. *Strophitus undulatus* (Say)
11. *Strophitus edentulus* (Say)
12. *Eurynia nasuta* (Say)
13. *Lampsilis radiata* (Gmel.)
14. *Lampsilis cariosa* (Say)
15. *Lampsilis ochracea* (Say)

It is to be remarked that no. 3, no. 10 and no. 15 are found exclusively in the tidewater region of the lower Delaware and Schuylkill, and that no. 3 is at the best extremely rare (only once reported), and that no. 10 is altogether a doubtful form. No. 1 is very local (uppermost Schuylkill).

All the others go up beyond tidewaters, and are found in the Delaware River or its tributaries on the Piedmont Plateau. The Allegheny Valley and its eastern boundary being obscured in this region, it practically is connected with the Piedmont Plateau. The Delaware River proper extends soon into the Glacial area, but there are tributaries outside of it west (northwest) of the Blue Mountain (Kittatinny Mountain), belonging to *Lehigh River*. The Lehigh itself is polluted; but I have collected in this region the following species (*Princess Cr.* and *Meniolagomeka Cr.*, at Kunkletown and Smith Gap, Monroe Co.; *Mahoning Cr.*, Leheighton, Carbon Co.; and *Lizard Cr.*, Mantz, Schuylkill Co.).

1. *Elliptio complanatus* (Dillw.)
2. *Anodonta cataracta* Say
3. *Alasmidonta heterodon* (Lea)
4. *Alasmidonta undulata* (Say)
5. *Alasmidonta varicosa* (Lam.)
6. *Strophitus edentulus* (Say)

Possibly the list is not quite complete (*Symphynota tappaniana* might be here). But I never found all of these species associated at a single locality, and it should be stated right here that it is a general rule that on the Atlantic side certain species are of rather erratic distribution, being sometimes missing at certain localities for no apparent reasons, while at others they may be abundant.

With the exception of *Margaritana margaritifera*, probably all of the Delaware River species (14) were once found in the lower part of *Schuylkill River*. Although the fauna of this river has been studied for nearly one hundred years, reliable information about the details of the distribution of the shells are not at hand. At the present time this river is so polluted that the fauna is extinct, only in the Schuylkill canal is a rather rich remnant of at least 8 species (nos. 2, 4, 5, 7, 8, 11, 12, 13 of list no. 17). Thus we cannot form an idea of how far the species advanced upstream and shall never know this.

In the headwaters of the *Little Schuylkill River*, in Schuylkill Co., northwest of Blue Mountain, a very peculiar species turns up,

Margaritana margaritifera, and still exists there, and I have collected it repeatedly in 1909 and 1910. But it has become very rare, and is restricted to some small, clear, and cold mountain runs, in which no other Najades are found. This species stands by itself, and, as we shall see below, needs special discussion.

II. The Fauna of the Susquehanna River.

The following is a list of the species, positively known to occur in the Susquehanna drainage:[5]

List No. 18.

1. *Elliptio complanatus* (Dillw.)
2. *Symphynota tappaniana* (Lea)
3. *Anodonta cataracta* Say
4. *Alasmidonta undulata* (Say)
5. *Alasmidonta marginata susquehannae* Ortm.
6. *Alasmidonta varicosa* (Lam.)
7. *Strophitus edentulus* (Say)
8. *Lampsilis radiata* (Gmel.)
9. *Lampsilis cariosa* (Say)

The lower Susquehanna, in Maryland, is unknown. Possibly, the lowland and tidewater species, *Elliptio fisherianus* and *Lampsilis ochracea*, might be found there. And further, *Alasmidonta heterodon* has not been taken in the Susquehanna drainage, although it is present to the north and south of it. Even adding these three species, the fauna of the Susquehanna falls short of that of the Delaware by three species; four seem to be absent (*Margaritana margaritifera, Anodonta implicata, Strophitus undulatus, Eurynia nasuta*), while *Alasmidonta marginata susquehannae* is added. The first two species surely reach their southern boundary in the Delaware drainage, while the doubtful *Strophitus undulatus* seems to be

[5] *Anodontoides ferussacianus* (Lea) has been reported from the headwaters of the Susquehanna in New York state. It is not found in Pennsylvania, and the New York record should be confirmed; but even when correct, this may be neglected, for this species surely does not belong to the original fauna of this system, but is a postglacial immigrant.

local, and *Eurynia nasuta* has been reported farther south on the Coastal Plain (as far as North Carolina by Simpson; from James River by Conrad, '36; from the lower Potomac by Dewey, '56; and Marshall, '95). But these localities should be confirmed, since this species has been frequently confounded with *Elliptio productus* and *fisherianus.* According to Rhoads ('04), it is also in Sussex and Kent Cos., in Delaware.

The Susquehanna drainage extends not only into the Allegheny Valley and into the mountains, but clear through the mountains, and encroaches upon the Allegheny plateau. All of the species mentioned above go up into this region, but two of them have only a limited distribution, and seem to be restricted to the larger rivers. These are *Lampsilis radiata* and *L. cariosa.* Both of them go in the North Branch to the New York state line. In the Juniata is only *L. cariosa* (up to Huntingdon, Huntingdon Co.), and in the West Branch both go up at least to Williamsport, Lycoming Co. In the real headwaters there are only seven species, and they are not always associated at a particular locality (generally there are only from three to six together).

One locality is of special interest: this is *Cush Cushion Creek,* in Greene Twp., Indiana Co. This is the most western point to which the Susquehanna fauna advances, and the following species are here:

1. *Elliptio complanatus* (Dillw.)
2. *Symphynota tappaniana* (Lea)
3. *Alasmidonta varicosa* (Lam.)
4. *Strophitus edentulus* (Say)

Not very far from here, in *Chest Creek,* Patton, Cambria Co., I found:

1. *Elliptio complanatus* (Dillw.)
2. *Symphynota tappaniana* (Lea)
3. *Alasmidonta undulata* (Say)
4. *Strophitus edentulus* (Say)

Also *Anodonta cataracta* Say has been found in this region, in *Beaver Dam Creek,* Flinton, Cambria Co. Thus there would be six

species in this uppermost part of the drainage of West Branch. *Alasmidonta marginata susquehannae* has not been found here.

The seven species of the upper Susquehanna drainage are the same as those of the Delaware, with the exceptions that in the former *Margaritana* and *Alasmidonta heterodon* are missing, while in their place *Symphynota tappaniana* and *Alasmidonta marginata susquehannae* turn up. Thus there are five species common to both drainages.

Further investigations may change this slightly. But this seems to be assured, that although similar faunas exist in both rivers, the Susquehanna falls short by several species of the Delaware, and that the lack is made good only in part by the presence of a local form, *Alasmidonta marginata susquehannae.*

III. The Fauna of the Potomac River.

The following species are positively known to exist in the Potomac drainage:

List No. 19.

1. *Elliptio complanatus* (Dillw.)
2. *Elliptio productus* (Conr.)
3. *Symphynota tappaniana* (Lea)
4. *Anodonta cataracta* Say
5. *Alasmidonta undulata* (Say)
6. *Alasmidonta varicosa* (Lam.)
7. *Strophitus edentulus* (Say)
8. *Lampsilis radiata* (Gmel.)
9. *Lampsilis ovata cohongoronta* Ortm.
10. *Lampsilis cariosa* (Say)
11. *Lampsilis ochracea* (Say)

In addition, there might be, in the lower Potomac, *Elliptio fisherianus* (Lea) and *Eurynia nasuta* (Say); these have been frequently confounded, but forms like them are positively known to occur in the Potomac at Washington. Possibly both of them are there. Further, there might be, in the tributaries on the Piedmont Plateau, *Alasmidonta heterodon* (Lea), which is found both to the north and south of the Potomac drainage.

No. 9, *Lampsilis ovata cohongoronta,* should be disregarded, and dropped from the list of the original fauna of the Potomac, for it probably is a modern introduction from the west (Ortmann, 1912*b*).

Thus, including the doubtful forms, there would be 13 species belonging to the Potomac drainage. This is two less than in the Delaware; while three of the latter are missing here (*Margaritana margaritifera, Anodonta implicata, Strophitus undulatus*), one other is added, *Elliptio productus.* This latter case is important, because we positively know that this species is a southern form, which reaches its most northern range in the Potomac.

Aside from *Elliptio fisherianus* and *Eurynia nasuta,* which, when present, are found only in the lower Potomac, three others, *Lampsilis radiata, cariosa,* and *ochracea,* are restricted to the lower parts of the drainage, below the gap in the Blue Ridge at Harper's Ferry. Above and to the west of this point, that is to say, in the Allegheny Valley and the Allegheny Mountains, only the following species are present (of course, disregarding the introduced no. 9):

1. *Elliptio complanatus* (Dillw.)
2. *Elliptio productus* (Conr.)
3. *Symphynota tappaniana* (Lea)
4. *Anodonta cataracta* Say
5. *Alasmidonta undulata* (Say)
6. *Alasmidonta varicosa* (Lam.)
7. *Strophitus edentulus* (Say)

Also here, seven species ascend into the headwaters, and among them there are again the same five (*Elliptio complanatus, Anodonta cataracta, Alasmidonta undulata, Alasmidonta varicosa, Strophitus edentulus*) which we have seen to be common to the headwaters of the Delaware and Susquehanna. An additional one, *Symphynota tappaniana,* is also found in the Susquehanna, while *Elliptio productus* is a new element in this fauna.

I do not think it necessary to give further particulars. But again it should be noted, that the distribution of these species is rather erratic, and that they generally are not all found associated. *Elliptio productus* has not been found yet in the region of the Alle-

gheny Valley (Antietam and Conodoguinet creeks in Maryland and Pennsylvania, Shenandoah River in the Virginias), but it is rather frequent in the Potomac and its tributaries in West Virginia, Maryland and Pennsylvania in the region of the Allegheny Mountains.

IV. The Fauna of Rappahannock River.

The *Rappahannock* is a Piedmont Plateau stream, and is entirely east of the Blue Ridge. I collected near the headwaters about Remington, Fauquier Co., and Culpepper and Rapidan, Culpepper Co., Va. The following is the list:

List No. 20.

1. *Elliptio complanatus* (Dillw.)
2. *Elliptio productus* (Conr.)
3. *Elliptio lanceolatus* (Lea)
4. *Symphynota tappaniana* (Lea)
5. *Alasmidonta heterodon* (Lea)
6. *Alasmidonta undulata* (Say)
7. *Strophitus edentulus* (Say)

I give this list only for comparison; probably it is not quite complete. The interesting points are, that *Alasmidonta heterodon* turns up here again, and that there is here a new, southern form, which does not go farther north (*Elliptio lanceolatus*).

V. The Fauna of the Upper James River.

I did not do any collecting in James River east of Blue Ridge, and although a few records are at hand from the lower James, it is impossible to give a complete list. West of Blue Ridge, the fauna of *North River* (called *Calf Pasture River* in its upper part) has been studied many years ago by Conrad (1846). I place his list by the side of the forms collected by myself in this region:

List No. 21.

Conrad's list:	Species collected by myself:
Unio subplanus Conr.	=1. *Lexingtonia subplana* (Conr.)
Unio purpureus Say	=2. *Elliptio complanatus* (Dillw.)

Unio lanceolatus Lea, probably	= 3. *Elliptio productus* (Conr.)
	4. *Symphynota tappaniana* (Lea)
Unio collinus Conr.	= 5. *Alasmidonta collina* (Conr.)
Alasmodon undulata Say	= 6. *Alasmidonta undulata* (Say)
	7. *Strophitus edentulus* (Say)
Unio constrictus Conr.	= 8. *Eurynia constricta* (Conr.)
Alasmodon marginata Say	
Anodon cataracta Say	
Anodon marginata? Say	

I did not find *U. lanceolatus*, but in its place *Ell. productus* is very abundant, so that, I believe, Conrad confused these two species. *Anodonta marginata* is given by him as doubtful, and we may rest assured that this (northern) species is not found here. But it is quite possible that *Alasmodon marginata* (now *Alasmidonta varicosa*) and *Anodonta cataracta* are here, and I do not hesitate to add these to my list. My list has two species, not mentioned by Conrad. Thus we would have ten species in the upper James drainage. The five species common to the headwaters of the more northern Atlantic streams are again here, there is one species (*Symphynota tappaniana*) known from upper Susquehanna and Potomac, one species (*Ell. productus*), known from upper Potomac, and three species, which turn up here for the first time:

Lexingtonia subplana
Alasmidonta collina
Eurynia constricta

These additional elements are undoubtedly more southern types, which reach here their most northern station.

VI. The Fauna of the Upper Roanoke River.

Only the uppermost *Roanoke* is known to me. It drains a relatively small portion of the Allegheny Valley, chiefly in Roanoke and Montgomery Cos., Va., and has the following, poor fauna:

List No. 22.

1. *Elliptio complanatus* (Dillw.)
2. *Strophitus edentulus* (Say)
3. *Eurynia constricta* (Conr.)

These species are all found in the upper James, and one of them (no. 3) clearly shows the affinity with that system. This is undoubtedly a depauperated fauna, corresponding to the small size of the streams. Possibly the record is not complete. Below Roanoke, the river is polluted, but east of the Blue Ridge there are surely additional species in this system.

Summary of Facts Concerning the Eastern Fauna.

Full list of all species known to exist on the Atlantic slope (in the region investigated):

List No. 23.

1. *Margaritana margaritifera* (L.)
2. *Lexingtonia subplana* (Conr.)
3. *Elliptio complanatus* (Dillw.)
4. *Elliptio fisherianus* (Lea)
5. *Elliptio productus* (Conr.)
6. *Elliptio lanceolatus* (Lea)
7. *Symphynota tappaniana* (Lea)
8. *Anodonta cataracta* Say
9. *Anodonta implicata* Say
10. *Alasmidonta collina* (Conr.)
11. *Alasmidonta heterodon* (Lea)
12. *Alasmidonta undulata* (Say)
13. *Alasmidonta marginata susquehannae* (Ortm.)
14. *Alasmidonta varicosa* (Lam.)
15. *Strophitus undulatus* (Say)
16. *Strophitus edentulus* (Say)
17. *Eurynia constricta* (Conr.)
18. *Eurynia nasuta* (Say)
19. *Lampsilis radiata* (Gmel.)
20. *Lampsilis cariosa* (Say)
21. *Lampsilis ochracea* (Say)

Lampsilis ovata cohongoronta Ortm. has been dropped as not indigenous on the Atlantic slope.

The following facts are observed:

1. Probably seven species of these have a rather general distribution. In five of them this is perfectly clear (nos. 3, 8, 12, 14, 16), but probably also nos. 7 and 11 fall under these; they only may have been overlooked in certain regions.

2. There are six forms, which apparently have a more northern range, disappearing toward the south, nos. 1, 9, 18, 19, 20, 21. The last four have the peculiarity in common that toward the south they become more or less restricted to the coastal plain.

3. On the other hand, there are six forms, which have their center more toward the south and disappear toward the north. These are the nos. 2, 4, 5, 6, 10, and 17.

4. Of the two remaining forms, no. 13 is a local form of the Susquehanna drainage, while no. 15 is altogether doubtful, but may be a local (tidewater) form of no. 16.

Compared with the western fauna of 47 species (list no. 1), the Atlantic fauna is decidedly poor (less than half the number of species). But in the Ohio we notice a general and marked decrease of species in the headwaters, so that there are only fourteen species in the headwaters of the Allegheny River. In the eastern drainage systems, there is also a slight decrease toward the headwater, but this is much less in proportion, and in the mountain region we have yet thirteen species (nos. 1, 2, 3, 5, 7, 8, 10, 11, 12, 13, 14, 16, 17). Thus we may say, that, disregarding a few species restricted to the lowlands and the larger rivers, *the fauna of the Atlantic streams remains, in each river system, rather uniform up to the headwaters,* decreasing hardly in the number of species.

Further, in the region of the headwaters of the Monongahela and Kanawha, the conditions are actually reversed. Here only very few species (not more than three) are found in the western streams, while the eastern streams (Potomac, James) have decidedly more, the James, for instance, at least eight, possibly ten. *Thus the Atlantic fauna is here richer than the western.*

But the Tennessee fauna (list no. 16) again holds its own, and the Atlantic fauna falls by far short of it.

Chapter 2.

Systematic Affinities of the Najades of the Interior Basin and of the Atlantic Slope.

In order to understand the mutual relations of the western and eastern faunas, which, as we have seen, are at present rather sharply distinguished, it is necessary to consider the systematic affinities of the forms belonging to either.

Up to a comparatively recent time the natural system of the Najades was extremely obscure. However, the great synopsis of Simpson (1900*a*) has paved the way for a proper understanding of the relationship of our Najades, and the more recent papers of the present writer (chiefly 1912*a*) have furnished what is believed to be the natural system, expressing, as far as possible, the genetic affinities within this group.

Using this system as a guide, the following remarks are to be made:

I. The general fauna of the upper Ohio drainage (list no. 1, p. 291) contains no less than seventeen genera, which are not found on the Atlantic side, namely:

Fusconaia	*Hemilastena*	*Amygdalonaias*
Crenodonta	*Ptychobranchus*	*Plagiola*
Quadrula	*Obliquaria*	*Paraptera*
Rotundaria	*Cyprogenia*	*Proptera*
Plethobasus	*Obovaria*	*Truncilla*
Pleurobema	*Nephronaias*	

This is entirely sufficient to show the tremendous difference between the two faunas, and demonstrates clearly that *the Allegheny Mountains formed an important barrier to the eastward distribution of the bulk of the western fauna.* No further discussion of this is required.

II. The fauna of the headwaters of the Allegheny River (combined lists 6, 7, 8, 9, p. 301) contains five species (out of fourteen) which are typically western and belong to genera just mentioned:

Fusconaia undata rubiginosa
Pleurobema obliquum coccineum
Pleurobema clava
Ptychobranchus phaseolus
Obovaria circulus lens

Another one, *Symphynota costata*, should be added, since, although the genus is found in the east, the subgenera are different (*Lasmigona* and *Symphynota*).

This shows that although a number of the typical western genera have gone way up into the headwaters, *they have not been able to cross the divide.*

III. On the Atlantic side (see list no. 23) we have two genera (*Margaritana* and *Lexingtonia*), which are not found in the interior basin. *Margaritana* has, indeed, a related form (*Cumberlandia monodonta* (Say)) in the Tennessee and Ohio drainage, but there is probably no direct genetic connection between them, and the history of *Margaritana*, as will be seen below, *is a case by itself.*

IV. *Lexingtonia* is possibly related to and descended from certain interior basin forms (such as *Fusconaia* and *Pleurobema*), but the relationship is remote, and for all practical purposes we may class it with the cases to be mentioned presently. These are the following forms (of list no. 23): nos. 3, 4, 5, 6 (the four species of *Elliptio*), and nos. 10, 11, 12 (*Alasmidonta collina, heterodon, undulata*). All these are forms of the respective genera, which have *no closely allied or representative forms on the western side*, although the genera are represented there.

Attention should be called to the fact that *Lexingtonia*, three species of *Elliptio* (*fisherianus, productus, lanceolatus*) and *Alasmidonta collina* undoubtedly belong to the *southern element* in the Atlantic fauna, and that their distribution northward is limited. However, it is also probable that *Elliptio complanatus, Alasmidonta heterodon* and *undulata* belong to the same class. The first and third are undoubtedly southern in their affinities, and allied species are frequent upon the southern portion of the Atlantic slope (in the Carolinas and Georgia). This is not so clear in the case of *Alasmidonta heterodon*. Here it has the appearance, as if the dis-

tribution might be more northern, but this may be due to defective knowledge of the facts.

V. Another group of Atlantic species *has closely allied species in the interior basin.* No. 17 of the list, *Eurynia* (*Micromya*) *constricta*, has a representative form in the upper Tennessee drainage (*Eurynia* (*Micromya*) *vanuxemensis*). Six others (nos. 8, 9, 14, 19, 20, 21) have closely related, indeed representative forms, in the upper Ohio drainage. The relation is as follows:

- no. 8 and 9, *Anodonta cataracta* and *implicata*, represent the western *Anodonta grandis*.
- no. 14, *Alasmidonta varicosa*, represents the western *Alasmidonta marginata*.
- no. 19, *Lampsilis radiata*, represents the western *Lampsilis luteola*.
- no. 20 and 21, *Lampsilis cariosa* and *ochracea*, represent the western *Lampsilis ovata ventricosa* (and its allied forms).

It should be noted that just these Atlantic forms are preëminently those which have a more northern range upon the Atlantic side.

VI. Finally, there are four species on the Atlantic side, *which are specifically identical with western forms.* Particulars are as follows:

- no. 13, *Alasmidonta marginata susquehannae*, is a local form of the Susquehanna drainage, closely resembling the widely distributed western *Alasmidonta marginata*.
- no. 7, *Symphynota tappaniana*, is represented on either side by an absolutely identical form. But here the distribution is rather general on the eastern side and local on the western (New River).
- no. 16, *Strophitus edentulus*, is absolutely identical on either side, and also widely distributed, east as well as west. But it should be noted that it is apparently absent in New River.
- no. 18, *Eurynia nasuta*. Here we see that the identical species is on the Atlantic side and in Lake Erie basin, but *not* in the upper Ohio drainage.

We see at once that these cases apparently are not subject to the same laws, and further below they shall be treated each by itself.

There remains yet one of the Atlantic forms, no. 15, *Strophitus*

undulatus. We must dismiss this for the present, for we do not know much about its taxonomic standing and its distribution. This may be nothing but a local form of *Strophitus edentulus,* and then it would have to the latter the same relation as *Lampsilis ochracea* has to *L. cariosa* (the former is the tidewater form of the latter).

As a whole, *the Atlantic fauna should be regarded as an offshoot of the fauna of the interior basin,* with the exception of *Margaritana margaritifera.* It does not possess any very strongly marked types of its own, but all may be traced back to western types. However, there are different elements on the Atlantic slope, which apparently reached their present range by different ways, and probably at different times. The greatest independence is shown among those which are found in the southern section of the Atlantic slope, and *there is an indication of the development of a secondary center of dispersal in this region,* producing a few characteristic types, more remote in their affinities from the forms of the interior basin. The other forms are generally more or less closely connected with western species, in fact, clearly are representative forms of them.

Chapter 3.

Distributional Facts in other Freshwater Animals.

Before we advance further in our attempt to study the mutual relations of the eastern and western freshwater faunas, it is well to compare a few other groups with the Najades, in order to ascertain whether there are parallel cases to those described above.

I. SPHAERIIDÆ.

For the identification of my material I am indebted to V. Sterki. Although I have collected a great many *Sphæriidæ* from the streams of Pennsylvania, West Virginia, and Virginia, my collections are by no means complete. Nevertheless, as far as they go, they serve to confirm the well-known fact, that with regard to these small shells, *the Alleghenian divide does not form an important faunistic boundary.* Thus the *Sphæriidæ* distinctly differ from the Najades, and undoubtedly must have been subject to other laws.

It is not necessary to give a detailed account of the single species; it suffices to enumerate those species which I have before me from both sides of the mountains:

Sphærium sulcatum (Lam.)
Sphærium solidulum (Pr.)
Sphærium stamineum (Conr.)
Sphærium striatinum (Lam.)
Musculium transversum (Say)
Musculium truncatum (Linsl.)
Pisidium virginicum (Gmel.)
Pisidium compressum Pr.

Of course, these examples will become more numerous when more exhausting studies have been made.

Altogether, we may safely assume that it is a general rule among this group, that the distribution is not influenced by the Alleghenian divide. As we have seen above, this condition is extremely rare among the Najades. In the present case, the distribution of the *Sphæriidæ* seems to have been formed under the influence of one great general factor, which probably is the faculty of these shells to cross over divides, presumably by being transported. It is very pertinent to bring this out here most emphatically, because, as we have seen, this factor has had very little or no effect among the Najades, as is shown by the entirely different character of their distribution.

II. GASTROPODA, FAMILY: PLEUROCERIDÆ.

The identifications have been kindly furnished by A. A. Hinkley. I have a rather satisfactory material of this family, although the records are not as complete and exhausting as in the Najades.

The whole character of the distribution of these freshwater snails is like that of the Najades, and, consequently, it is indicated that no exceptional means of dispersal (transport) have played a part. The range of the species follows rather closely the river systems, and *the effect of the Alleghenian divide as a barrier is quite evident.* Two facts, however, are to be regretted, first, that in the region

investigated the number of species is not very great, and second, that the natural affinities within this family are yet entirely obscure. Nevertheless, some interesting points are easily observed, as will be seen from the following account.

A. The upper Ohio drainage in western Pennsylvania and West Virginia has the following species:

1. *Pleurocera canaliculatum* (Say)
2. *Pleurocera altipetum* Anth.
3. *Goniobasis livescens* (Mke.)
   (incl. var. *depygis* (Say))
4. *Goniobasis translucens* Anth.
5. *Anculosa dilatata* (Conr.)

It is to be remarked that the two Pleuroceras are restricted to the larger rivers; no. 1 is in the Ohio proper at and below Pittsburgh, and has also been found as far up as the lower Youghiogheny in Allegheny Co., Pa.; while no. 2 is in the middle Allegheny up to Venango and Warren Cos. No *Pleuroceras* have ever been found in any of the smaller streams.

Goniobasis livescens is in the Beaver drainage, and in that of French Creek of the Allegheny (also in Lake Erie), and it appears as if this species should be classed with those Najades which have been mentioned (on p. 291, footnote 2) to be peculiar to those drainages. The *Goniobasis*-species of the Allegheny River, beginning in the Ohio River below Pittsburgh, and going up through Armstrong, Venango, Forest to Warren Co., is, according to Hinkley, *G. translucens,* and this species is also abundant in the drainages of Beaver River and French Creek.

Except in the lower Youghiogheny, where (many years ago) *Pleurocera canaliculatum* has been found, no species of *Pleurocera* or *Goniobasis* are known from the whole Monongahela drainage. I have no doubt that some existed once at least in the lower Monongahela, but the pollution of the waters apparently has exterminated them, and no records have been preserved. The upper Youghiogheny, where the water is clear, is entirely without *Pleuroceridæ,* and this is positively established, for a search has been made for them.

This is a fact which should be emphasized, for in the headwaters of the Monongahela, *Anculosa dilatata* turns up. This is found in the lower part of the Cheat at Cheat Haven, Fayette Co., Pa., and goes up through the canyon into the headwaters (Shavers Fork, Parsons, Tucker Co., W. Va.); it is also in Tygart Valley River, at Elkins, Randolph Co., W. Va., and even in the plateau stream, West Fork River, at Lynch Mines, Harrison Co., W. Va.

No *Anculosas* are found in the rest of the upper Ohio drainage in western Pennsylvania.

Farther south in West Virginia our knowledge probably is fragmentary. In the *Kanawha drainage,* no *Pleuroceridæ* are known to me, except *Pleurocera validum* Anth. in Elk River; and New River and Greenbrier rivers, at least from Hinton upward, contain *Anculosa dilatata* (Conr.). The latter is exceedingly abundant in this region.

In the *Big Sandy,* at Prestonsburg, Floyd Co., Ky., I collected *Pleurocera unciale* Hald., a species which is also found in Clinch River. *Licking River* at Farmer, Rowan Co., Ky., has *Pleurocera cylindraceum* Lea.

It appears that there is a certain correlation in the distribution of the *Pleuroceridæ* and the *Najades* of the upper Ohio drainage, at least as far as it concerns the genera *Pleurocera* and *Goniobasis.* It is well known that the greatest variety of forms is found in the lower Ohio and its tributaries, and it is suggested that this fauna has migrated upstream, and that there is a general decrease in the number of species in an upstream direction. *But the different tributaries of the upper Ohio seem to have received or have developed different species.* In addition, most of the species do not go very far into the headwaters, and the smaller streams generally do not contain *Pleuroceridæ,* or only rarely so.[6]

One very remarkable fact is to be noted. In the headwaters of the Monongahela, excluding the Youghiogheny, and also in the headwaters of the Kanawha (New and Greenbrier rivers), *Anculosa*

[6] This, however, is different in the Beaver drainage, where species of *Goniobasis* are found in small creeks. But the characteristic species, *G. livescens,* probably did not come up the Ohio, but came "across country" from the West.

is the only genus found, and it is represented in all these streams by one and the same species, A. dilatata. This genus is not found anywhere else in the whole upper Ohio drainage in West Virginia and Pennsylvania, but it is represented on the Atlantic side by a closely allied and widely distributed species. It is perfectly clear that this case does not submit to the same laws which governed the Najad fauna and the other *Pleuroceridæ* of this region. Further particulars will be given below.

As regards the *upper Tennessee* fauna (Clinch and Holston rivers), we have here again a rich development of *Pleuroceridæ*, as is well known. I do not think that my collections represent this fauna fully, but I have collected the following species:

1. *Io fluvialis* (Say) (Holston and Clinch)
2. *Pleurocera estabrooki* (Lea) (Holston)
3. *Pleurocera knoxense* (Lea) (Holston)
4. *Pleurocera unciale* Hald. (Clinch, also, as we have seen, in Big Sandy.)
5. *Goniobasis simplex* (Say) (Holston and Clinch)
6. *Anculosa gibbosa* Lea (Holston and Clinch)

Io is a type entirely peculiar to this region. Except *Pl. unciale*, which is also in the Big Sandy, the others have no striking relationship to any of the species mentioned above from the upper Ohio. The *Anculosa* may have a somewhat closer genetic relationship with the *Anculosas* farther north, in New River, etc., but morphologically they are distinctly separated.

Thus it is clear that the *Pleurocerid*-fauna of the upper Tennessee undoubtedly corresponds to the Najad-fauna of this region, and probably has had a similar history.

B. Pleuroceridæ of the Atlantic Side.

The genus *Pleurocera* is entirely missing on the Atlantic side. *Goniobasis* is represented by two species:[7] *G. virginica* (Gmel.) and

[7] Additional species are found from North Carolina southward. *G. nickliniana* Lea has been reported (Tryon, '66, p. 31) from Bath Co., Va. (original locality: near Hot Springs, drainage of Jackson River). This species is unknown to me. I collected in Jackson River at Covington, Alleghany Co.,

G. symmetrica Hald. The former is common all over the Delaware, Susquehanna, Potomac and James river drainages, and has been found practically everywhere, possibly with the exception of the smallest streams in the headwaters. This species has no closely allied or representative form in the upper Ohio drainage, but if Tryon's arrangement of the species (1866, p. 39 f.) is natural, related forms are found in Tennessee and Alabama. It is unknown how far this species ranges southward, but according to our present knowledge, it seems that it belongs rather to that group of freshwater forms, *which point in their affinities to a center lying on the southern Atlantic slope.*

Specimens of a *Goniobasis* collected by myself in Mason Creek, Salem, and Tinker Creek, Roanoke, Roanoke Co., Va. (Roanoke drainage) have been identified by Hinkley as *G. symmetrica*, a species reported (Tryon, '66, p. 30) from West Virginia, East Tennessee, South Carolina, North Georgia, and Alabama. But there is much uncertainty about this, and West Virginia seems to be more than doubtful. One fact, however, is sure: this species is not found north of the Roanoke on the Atlantic side. *Thus also this appears as a southern type*, and should be classed with the same group as *G. virginica*.

In addition there is a species of *Anculosa* on the Atlantic side: *A. carinata* (Brug.). This is absent in the Delaware drainage, but extremely abundant in the systems of the Susquehanna, Potomac, James, and Roanoke, and goes far up in the mountain streams. This species is very closely allied to *A. dilatata* of New River and the headwaters of the Monongahela, and undoubtedly stands in closest genetic relationship to it. In fact, these two species are so intimately allied on the one hand and are so polymorphous on the other, that it is extremely hard to distinguish them. It has been mentioned that they also have an allied but more sharply distinguished species in the upper Tennessee (*A. gibbosa*).

There is no doubt that we have to class this case with those of *the very closely allied or identical species of Najades on either side*

less than twenty miles from Hot Springs, but only *Anculosa carinata* was there, in various forms, some of which resemble very much Lea's figure of *G. nickliniana*.

of the divide. The present case most resembles that of *Symphynota tappaniana,* where we have a species found both in New River and on the Atlantic side. The range of the latter is not entirely identical, for it is not found in the Monongahela drainage, and goes, on the Atlantic side, farther north, while *A. carinata* only reaches the Susquehanna in which it goes up to New York state.

III. FAMILY: VIVIPARIDÆ; GENUS: CAMPELOMA RAF.

Also in this group we lack a modern revision of the species, and there is much uncertainty with regard to the geographical distribution. What I have collected in Pennsylvania, West Virginia and Virginia apparently falls under three described species: *Campeloma decisum* (Say), *C. rufum* (Hald.), and *C. ponderosum* (Say), and with the first one I unite as undistinguishable, what has been called *C. integrum* (Say). At any rate, I am not able to distinguish the common form of the upper Ohio drainage in western Pennsylvania and West Virginia from the common form of the Atlantic side (from Delaware to James). The identical form is also in Clinch River.

C. decisum seems to prefer the larger rivers, but it is not absent in the headwaters, and I have it from the mountain region on either side of the divide (Shaver's Fork, upper Tygart system, Greenbrier, uppermost tributaries of Allegheny, and many places in the headwaters of the Potomac and James). Consequently, this would be again a case where *an identical species is found on either side of the divide,* and where this divide does not form a barrier to the distribution.

Of the other two species, *C. rufum* is known to me only from northwestern Pennsylvania, in the Allegheny and its tributaries (French Creek) and in the Beaver and Little Beaver drainage. This looks very much as if it belonged to those forms, *which invaded Pennsylvania from the west,* coming "across country." (After all, this may be only a local form of *C. decisum,* with which it is often found associated.)

I found *C. ponderosum* only in Elk Creek, West Virginia, and farther down in the Ohio (Portsmouth, Scioto Co., Ohio). Here it

is the only *Campeloma* present, and it should be emphasized that in the upper Kanawha drainage, in Greenbrier River, not this species, but *C. decisum* is found.

C. rufum and *ponderosum* have no representatives on the Atlantic side, and clearly belong to the fauna of the upper Ohio River, although they probably belong to different parts of it.

IV. DECAPOD CRUSTACEANS: THE CRAYFISHES OF THE GENUS CAMBARUS.

The conditions presented by the distribution of the crayfishes have been discussed by the writer with regard to the state of Pennsylvania (Ortmann, 1906). These studies have been continued toward the south, and most of the facts given here for Virginia and West Virginia are new and add considerably to our previous knowledge. Of course, a certain ecological group is to be disregarded here, the burrowing crayfishes, for they do not live in open water, rivers or creeks, and do not depend in their distribution on drainage systems (*Cambarus carolinus* Er., *C. monongalensis* Ortm., *C. diogenes* Gir.).

A. The following river and creek forms are found on the WESTERN SIDE of the mountains.

Cambarus obscurus Hag. This species belongs to the upper Ohio system, from Moundsville, W. Va., in the Ohio, and from Fishing and Fish Creek upward. But it should be noted that subsequent investigations have shown that it goes a little farther down in the Ohio proper, for it is in the river at St. Mary's, Pleasants Co., W. Va. In the Allegheny River this species goes up to the headwaters (Coudersport, Potter Co., Pa.), and also in the tributaries (Red Bank, Mahoning, Crooked), except in the Kiskiminetas-Conemaugh, where it goes only to the mouth of the canyon at Blairsville, while it goes up into the upper Loyalhanna in Westmoreland Co. Thus the Conemaugh resembles the conditions seen in the more southern mountain tributaries of the Monongahela. In the latter this species goes only to the lower end of the canyons, and is not found in the upper parts (Youghiogheny, Cheat, Tygart), while in the plateau stream, West Fork River, it is found nearly to the sources (Weston, Lewis Co., W. Va.).

Cambarus propinquus sanborni Fax. As has been shown in my previous paper, this species takes the place of *C. obscurus* as the river-species below the lower boundary of the range of the latter. In the Ohio proper, *C. propinquus sanborni* has been found at Parkersburg, Wood Co., and at Ravenswood, Jackson Co., W. Va. It is also present in the tributaries of the Ohio in this region. An additional locality in the drainage of Middle Island Creek is McKim Creek, Union Mills, Pleasants Co., W. Va. It is in the Little Kanawha drainage in North Fork Hughes River, Cornwallis, Ritchie Co., and in the Little Kanawha River, Burnsville, Braxton Co., W. Va.[8] From the Kanawha drainage I have it from Elk River, Clay, Clay Co., and I collected it also in Mud River, Milton, Cabell Co., which is in the Guyandot drainage. Although I did not get it in the Big Sandy, it is surely there, for its type locality (according to Faxon) is Smoky Creek, Carter Co., Ky. (I could not locate this creek, but a place called Smoky Valley is in western Carter Co., and is in the Tygart Creek drainage; Little Sandy and Tygart Creek fall into the Ohio below the mouth of the Big Sandy.) Beyond this, this species disappears, and its place is taken by the next, but I have ascertained this only in Rowan and Fleming Cos., Ky.

Cambarus rusticus Gir. This is the river-species of Licking River, which flows into the Ohio below Cincinnati. The old record for this species, Cincinnati, would thus be confirmed. I found this species in Licking River proper at Farmer, Rowan Co., and in the tributaries, Triplet Creek, Morehead, Rowan Co., and Fleming Creek, Pleasant Valley, Nicholas Co., Ky.

Cambarus spinosus Bund. This is the representative species of *C. rusticus* in the upper Tennessee drainage, and I found it in Clinch River at Richland and Raven, Tazewell Co., Va. From this center of distribution it has crossed over into the Gulf and Atlantic drainages in Georgia and South Carolina, but this does not concern us here.

In a general way, these river crayfishes show the same geographical features as the bulk of the Ohio River shell fauna. The species

[8] These two localities are interesting, for they approach closely localities in the West Fork River, at Lynch Mines, Harrison Co., and Weston, Lewis Co., where *C. obscurus* is found.

of the propinquus group (*obscurus* and *propinquus sanborni*) have the same peculiarity as the Najades, in going up, in the rivers, only to the falls line in the mountain streams of West Virginia and southern Pennsylvania, while in the upper Allegheny they go up nearly to the sources. The fact that in the Kiskiminetas-Conemaugh they do not follow the Najades into Somerset Co., and that thus this river resembles the southern ones; and that then again the upper Loyalhanna conforms with the northern streams, is not very astonishing, for the Kiskiminetas system, being geographically intermediate, should also be expected to form faunistically a transition.

These crayfishes, however, differ from the Najades, in presenting a uniformity of the upper Ohio fauna only in so far as they are systematically closely allied, belonging all into the same natural group. But specifically they are quite sharply distinct, and *thus indicate, in their distribution, three faunistically different sections:* the upper Ohio is characterized by *C. obscurus,* farther down *C. propinquus sanborni* takes its place, and finally, beginning with Licking River, *C. rusticus* turns up, and this species has a representative also in the upper Tennessee, *C. spinosus.*

These conditions are important for the history of the crayfish fauna of the Ohio basin, and suggest, as I believe, that the Najad and the crayfish population of this system was not entirely subject to the same laws.

Cambarus bartoni (Fabr.). This is not a river species, but a species of the small and smallest creeks, going up to the very springs. It is found everywhere on the western side of the mountains, for instance, Blackwater River and Shaver's Fork, small runs tributary to Buckhannon River, upper New River drainage (Reed Creek), and small runs tributary to Clinch River. It is also on the Atlantic side (see below).

Cambarus longulus Gir. Is found, on the western side, only in the upper Kanawha drainage, Greenbrier and New Rivers, and also in the upper Tennessee drainage, Holston and Clinch. It is also on the Atlantic side (see below).

B. Crayfishes of the Atlantic Side.

Cambarus blandingi (Harl.). This species has not been treated in my report on the Pennsylvanian crayfishes, but I have discovered subsequently that it is present in great numbers in the ditches of the Delaware meadows at League Island, Philadelphia. Its distribution is from New Jersey to Georgia, and in a slightly different form (var. *acutus* Gir.) it extends westward over the Gulf plain to Texas, and northward into the interior basin. The existence of related species chiefly upon the Gulf plain (Ortmann, 1905, p. 105) indicates that the *center of this species is in the southeastern United States*, and there is no question that it reached our section (from Virginia northward) by migration coming from the south. Thus it clearly belongs into the same group to which those Najades belong, for which we have located the center of dispersal in the southern parts of the Atlantic slope.

Cambarus limosus (Raf.) A species confined primarily to the lowlands and Piedmont region from New Jersey to Virginia, but which has gone up, in the Susquehanna and Potomac, into the mountains, possibly only secondarily. The facts of the distribution have been compiled in my former paper (1906, pp. 425 ff.), and the conclusion was reached (p. 432) that this is a form *belonging to the northern section of the Atlantic slope*, and that its connection with the western forms allied to it is around the northern end of the Appalachians. Thus it clearly falls into the same category with certain Najades mentioned above.

Cambarus obscurus Hag. This western species exists in the upper Potomac drainage. I have previously (1906) considered this as an accidental introduction, and more recently (1912*b*, pp. 51–54) I have parallelized this case with that of *Lampsilis ventricosa cohongoronta*, as due to artificial transplantation. Thus this is not an original feature of the Potomac drainage, and should be disregarded.

Cambarus acuminatus Fax. A species, known hitherto from the Atlantic drainage only in North and South Carolina, and also reported from French Broad River in North Carolina, tributary to the Tennessee. On the Atlantic side, however, this species extends farther north, and I have found it in Mason Creek, at Salem, and

in Tinker Creek, at Roanoke, Roanoke Co., Va. (Roanoke drainage), and in Mountain Run, Culpepper, Culpepper Co., Va. (Rappahannock drainage). Although differing from *C. blandingi* in not belonging to the coastal plain, but rather to the Piedmont plateau, or even the mountains, the direction of its distribution apparently was the same, from south to north, and thus it clearly *belongs to the southern element of the Atlantic fauna*. In the fact that the same species is also found in the Tennessee drainage, it resembles to a degree the case of *Eurynia constricta* and *vanuxemensis* among the Najades. But this may be disregarded for the present, for it does not concern the region under discussion.

Cambarus bartoni (Fabr.). All over the Atlantic side, also south of Pennsylvania, and I collected it myself, for instance, at Charlottesville, Albemarle Co., Va., and additional records are to be found in my former list of localities (1906, pp. 382–384). Here we have *a species of wide and general distribution both on the western and eastern side of the mountains,* going up into the very headwaters within the mountains. Thus it is clear that the divide has not acted as a barrier in this case, which I have explained by the exceptional means of dispersal possessed by this species in consequence of its ecological habits. This species is able to cross divides.

Cambarus longulus Gir. We have seen that this is in the upper Tennessee and the upper Kanawha, on the western side. On the eastern side it is a common form in the upper James drainage (Jackson and North Rivers). It also has been reported from the uppermost Shenandoah drainage, South River at Waynesboro, Augusta Co., Va.

This distribution clearly resembles that of *Symphynota tappaniana* among the Najades, and that of the genus *Anculosa* among the *Pleuroceridæ,* and there is no question that similar factors have contributed to bring this about, although in each of these cases certain peculiarities are observed. We shall devote more time to this farther below.

Chapter 4.

Summary of Distributional Facts which call for an Explanation.

The above is the faunistic material which I have been able to collect. Comparing the facts observed in the different groups of freshwater animals discussed, several classes have been brought to our attention repeatedly, and they may be condensed under the following generalized heads.

I. Western Side.

1. *The Alleghenian divide actually forms a sharp faunistic boundary for a great number of freshwater creatures.* This is most evident for the forms of the interior basin, which go up to a greater or lesser distance in the upper Ohio drainage, but do not cross the divide. To these belongs the bulk of the *Najad*-fauna; the genus *Pleurocera* and the western species of *Goniobasis,* among the *Pleuroceridæ;* at least one species of *Campeloma* (*C. ponderosum*); and the group of *Cambarus rusticus* and *propinquus* of the crayfishes (which are closely allied).

In a general way *the interior basin fauna appears as a unit,* a number of species, chiefly *Najades,* being found uniformly in all parts of the Ohio drainage, from the upper Tennessee region to the upper Allegheny River.

2. Nevertheless there are indications of a *differentiation into several subdivisions,* which may be described as follows:

(*a*) The most sharply differentiated part is the *upper Tennessee region,* and to this belongs probably the whole Cumberland-Tennessee drainage. This is clearly seen in the *Najades,* in the *Pleuroceridæ,* and in the existence of a peculiar species of crayfish, *Cambarus spinosus,* belonging to the *rusticus* group.

(*b*) Another part comprises the *main fauna of the Ohio,* chiefly of the middle and upper parts, and its tributaries. This fauna shows preëminently the *uniformity* mentioned above, and goes from Licking and Big Sandy rivers in Kentucky to the upper Allegheny, including the Kanawha and Monongahela. In the Allegheny this fauna goes to the headwaters. But in the Kanawha and Monon-

gahela *it goes only up to a point at the lower end of the canyon* of the mountain tributaries. This latter feature is expressed in the *Najades,* and also in the genera *Pleurocera* and *Goniobasis* in the *Pleuroceridæ.* Also the crayfishes of the *propinquus*-group (*Cambarus propinquus sanborni* and *C. obscurus*) show it distinctly.

(*c*) A third part is the *region of the headwaters of the mountain streams,* tributary to Kanawha (New and Greenbrier) and Monongahela (Buckhannon, Tygart, Cheat, Youghiogheny). This fauna is chiefly characterized by *negative* features, by the absence of the typical forms of the upper Ohio (2*b*). But it also has some *positive* characters; for instance, the presence of *Symphynota tappaniana* in the upper Kanawha; of *Anculosa dilatata* in the upper Kanawha, Tygart, and Cheat; and of *Cambarus longulus* in the upper Kanawha. Of the various streams belonging to this region, each has some features of its own, and the elements have various relations to each other. It is very important to notice that most of the forms found in these streams are *represented, on the Atlantic side, by identical or very closely allied forms* (*Symphynota tappaniana, Strophitus edentulus, Anculosa dilatata, Cambarus longulus*). Other elements of this fauna belong to the general Ohio fauna (*Symphynota costata, Elliptio dilatatus, Alasmidonta marginata*), and just these have no closely allied forms on the Atlantic side (*Alasmidonta varicosa* is indeed allied to *A. marginata,* but as we shall see, it is not closely connected with the New River form).

It further should be noted that the New River shows relations to the upper Tennessee in *Cambarus longulus,* and possibly also in *Anculosa.* Further, the upper Kiskiminetas-Conemaugh drainage in Pennsylvania shows an intermediate condition between the more southern mountain streams and the more northern tributaries of the Allegheny; with regard to the *Najades* it conforms to the latter, with regard to the *crayfishes* to the former (excepting again the Loyalhanna).

II. Eastern Side.

1. The fauna of the Atlantic slope shows little evidence that it ever was an important, independent center of radiation. All forms belonging to it have more or less close relations to forms of the

interior basin (except *Margaritana*). A certain *uniformity* of this fauna is also expressed in two ways:

(*a*) By the *uniform and wide distribution of certain species*, indicating the possibility of intermigration between the various river systems;

(*b*) by the fact that the fauna of each river, disregarding a few lowland species, *goes up, in its bulk, into the mountains* and approaches closely the headwaters without appreciable depauperation.

2. There is a *differentiation of elements* within the Atlantic fauna, indicating different origin.

(*a*) A *southern element* pointing to a secondary center of radiation in the southern parts of the Atlantic slope is distinguishable. This center itself, however, lies chiefly outside of the region discussed here. Forms like *Lexingtonia*, like those of the *Elliptio complanatus* and *fisherianus*-group, *Alasmidonta collina, heterodon*, and *undulata, Eurynia constricta*, among the *Najades, Goniobasis virginica* and *symmetrica* among the *Pleuroceridæ, Cambarus blandingi* and *acuminatus*, among the crayfishes, belong here. These forms exhibit morphologically the greatest independence, and are possibly the oldest element in the Atlantic fauna. In some cases it is hard or impossible to connect them with types of the interior basin by more than general relationship.[9]

(*b*) In the *northern section of the Atlantic slope exists a group of forms*, which are more closely related to species of the interior basin and often must be regarded as their direct representatives. These are the *Najades* enumerated under group V. (p. 325), and the crayfish, *Cambarus limosus*. They all have their main range in the north, and toward the south they disappear sooner or later, and have no representatives in the south. Very often their southward range becomes restricted to the coastal plain.

(*c*) Further, there is a third group among the Atlantic forms. *These are either conspecific with western forms or extremely closely allied*. These are the *Najades* mentioned under VI. (p. 325), the

[9] It might be mentioned here, that these forms probably will be intimately connected with the Tennessee-Coosa problem, and their number will be greatly added to, when the fauna of the Carolinas and of Georgia is taken into consideration.

Sphæriidæ, the *Anculosa dilatata-carinata* group of the *Pleuroceridæ*, *Campeloma decisum*, and the crayfishes, *Cambarus bartoni* and *longulus* (I disregard, for the present, *C. spinosus* and *C. acuminatus*, as probably belonging to the Tennessee-Coosa problem, at any rate to a region lying to the south of the one which interests us here).

These forms generally go way up into the mountains, and practically meet there with the western range of the respective forms, so that the distribution seems almost continuous across the mountains, and suggests crossing of the divide.

There is great variety in the details of distribution of these forms, and two main groups may be distinguished: those with a more universal range on either side of the mountains, and those with a more restricted range on one or on both sides.

The above is a sketch of the chief distributional features, and we see that it is possible to group a number of cases under the same heads, which means to say that very likely similar causes have acted to bring about similar distribution. But before we begin the task to investigate the laws which governed these different types of distribution, it is necessary to recall to our mind certain fundamental facts with regard to the physiography of the Alleghenies.

Chapter 5.

Physiographical Facts. History of the Allegheny Mountain Region.

The origin and the development of the Appalachian or Alleghenian mountain system is rather well worked out (see McGee, 1888, Davis, 1889, Davis, 1891, Willis, 1896, Hayes, 1896, Davis, 1907), and we may assume that its general features are established. We do not need to go much into detail here, but certain phases in the mountain forming process should be brought out, which will be important for our present purpose.

A. Formation of Mountains by Upheaval and Erosion.

Lateral pression in a general direction from northwest to southeast, in Permian and Postpermian times, formed the ancient and original Alleghenian system, which consisted of a number of more or less parallel folds (anticlines and synclines) running in a northeast-southwest direction. These folds were pressed up against an old block of Archaic rocks lying to the east of them, the Old Appalachian belt of Davis (1907), now Piedmont plateau. They were piled up highest in the eastern part, close to the old Archaic rocks, but also in the southern parts the elevation was originally higher than in the northern, and in this section not only folds, but also faults, were formed.

As soon as this mountain system began to develop, erosion set in. The original drainage features conformed to the original structure; the highest elevation being well to the east, the divide was situated here, close to the old Archaic land, and the old rivers had to follow the structure of the mountains, running first between the parallel ridges in consequent, synclinal valleys, and finding their outlets at certain points in a westerly (northwesterly) direction, toward the interior basin. On the other side, toward the Atlantic Ocean, there were shorter streams, originating also on the highest elevation, running east and southeast, and reaching the sea after having traversed the belt of Archaic rocks.

The longitudinal streams on the western side of the divide began to carve out their valleys. But in addition, on top of the anticlines, anticlinal valleys began to develop, running parallel to the synclinal valleys, and very soon an important differentiation in the power of erosion of these streams became evident, which is due to the geological structure and succession of rocks of the mountains. The beds which compose them are all archaic and palaeozoic; but while the uppermost (Carboniferous) consist largely of hard sandstones, in the lower beds (Devonian and older) softer shales and limestones prevail. While the oldest rivers were running uniformly over sandstones, the anticlinal rivers, and chiefly those running on the highest elevations, had the best chance to cut first through the sandstones and reach the softer beds below. After this, these streams working

in a less resistant material, had the advantage, and thus the anticlinal valleys were more deeply excavated than the synclinal valleys. This process advanced farthest in the eastern section of the mountains, so that what was once the highest elevation became finally a deeply excavated valley.

This general process was repeatedly interrupted by the fact that the whole region was reduced to base level. One of these periods of base level conditions is most important to us, that of Cretaceous times, when most of the mountain region was a peneplain, little elevated above the sea, but with certain hills (monadnocks) standing above this level. In Postcretaceous times a reëlevation took place, and the rivers began their work again, according to the same laws, but with complications due to the base-level period. During the latter, they had acquired courses across the strike of the mountains, and these were inherited by the later rivers, and often they were compelled to cut across hard rocks, thus forming so-called water gaps, which have no apparent connection with the original geological structure.

The difference in the erosion has produced a physiographical differentiation within the whole system. In the western parts, where the Pre-Carboniferous soft rocks have not been reached, either synclinal valleys are present, or the drainage system is independent on the structure, irregular or dendritic. This section has been base-leveled rather completely in the past, and thus it is of the character of a plateau, and has been called the *Alleghenian Plateau*. The eastern parts, which were originally much higher, have been much cut into by the anticlinal streams, which have carved out broad limestone valleys, with high ridges of harder rock between them, so that this region has a more mountainous character, and is known as the *Allegheny Mountains* proper. Within these mountains, farthest to to the east, where there was once the highest elevation, an exceptionally broad valley has been excavated, called the *Great Allegheny Valley*.

Thus we have, going from west to east across the mountains (see Plate XII.): (1) *The Allegheny Plateau;* (2) *the Allegheny Mountains,* with numerous ridges and valleys, the most eastern valley being

the *Great Allegheny Valley,* then follows, east of the mountains, a much older section of the country; (3) *the Piedmont Plateau,* a peneplain, the remnant of the Old Appalachian land; and finally toward the ocean comes an additional physiographic division, (4) the *Coastal Plain,* lying between the Piedmont Plateau and the sea, of various width, which consists of marine deposits of much younger geological age (Cretaceous and Tertiary) (see McGee, 1888, Powell, 1896, Davis, 1907).

In the southern Appalachians this division is somewhat modified. The boundary between 2 and 3 is more developed (Blue Ridge) and is called the *Appalachian Mountains,* while no. 2 has more of a valley character and is called *Appalachian Valley.* No. 1 is called *Cumberland Plateau* (see Hayes, 1899, Pl. 1).

The boundary between the *Coastal Plain* and the *Piedmont Plateau* is well marked by an escarpment forming a falls line for the streams traversing the Piedmont Plateau. The *Allegheny Mountains,* and chiefly the *Allegheny Valley,* are marked off from the *Piedmont Plateau* by the flank of an anticline, consisting largely of archaic rocks, known in Virginia as *Blue Ridge,* and continued into Pennsylvania as *South Mountain.* But farther north this ridge becomes obscure, and Piedmont Plateau and Allegheny Valley are more or less indistinct. In southern Virginia the Blue Ridge widens out and becomes a more important member of the system, finally reaching in North Carolina the highest elevation (see above). The *Great Allegheny Valley* is very distinct northwards, in Pennsylvania, Maryland and northern Virginia, forming a broad and flat limestone valley, and is sharply differentiated from the more western mountains and valleys. Farther south it merges more or less with the mountain region, which consists of several broad and flat limestone valleys, separated by longitudinal ridges formed by monoclinal harder rocks.

The boundary between the *Allegheny Mountains* and the *Allegheny Plateau* is well marked in Pennsylvania and Maryland by the western flank of an anticline, known as *Allegheny Front.* Farther south this may be traced to a certain distance,[10] but then, in West

[10] Willis, 1896, p. 186 (also Abbe, 1899, p. 70), use the name Allegheny Front much farther South, for the escarpment west of Bluestone River: this

Virginia, the mountain-type of erosion encroaches upon the plateau, and, for instance, the valley of the upper Tygart and Greenbrier valley are largely anticlinal valleys of the mountain-type (see Fontaine, 1876, p. 9), so that the eastern edge of the Allegheny Plateau is pushed back westward. In the region between James and New River and beyond (toward the southwest), conditions become more complex by the development of faults, and here the eastern edge of the plateau (Cumberland Plateau) is formed by a tremendous fault, which brings the Carboniferous down to about the same level with the Cambrian. (See maps and profiles in Rogers, 1884; also geological map by Willis, 1912; as to the faulting, see Lesley, 1865; Stevenson, 1887; Powell, 1896, p. 79.)

B. Stream Capture.

There is yet another factor which contributed to make the structure of the Alleghenies more complex. We have seen that the original divide of the waters probably was well to the east, not far from the old Piedmont land. It is clear that from this divide the way to sea-level (the Atlantic Ocean) was short and direct, while westward it was long and devious. This produced a much steeper grade of the eastern streams, and consequently the eroding power of the latter must have been much greater than that of the western streams. The eastern rivers had thus the first chance to saw through the divides westward. This resulted in the general law that the Atlantic streams have the tendency to cut into and to encroach upon the region which originally drained westward. This general law is not without exceptions, but such are rare.

Also the Atlantic streams have been subject to stream capture between themselves; Campbell (1896, p. 675) points out the unsymmetrical development of their basins, with the divides shifting toward the southwest; the Susquehanna developed at the expense of the Potomac, the Potomac at the expense of the James, the James at that of the Roanoke. Similar conditions probably existed on the western side.

is correct only in so far as this escarpment represents the eastern boundary of the Allegheny Plateau, but it does not correspond to the same structural line as the Allegheny Front in Pennsylvania.

This stream piracy or capture must have gone on all through the history of the mountains; but the evidence for the older cases is largely lost on account of the base level conditions prevailing at various times. Only more recent (Postcretaceous) cases are more or less clear. But in a general way the present rivers indicate that stream capture has been most effective in the northern parts of the Alleghenies, and, toward the south, the various rivers show this phenomenon in a lesser degree. (Davis, 1889; Hayes and Campbell, 1894, p. 102; also Campbell, 1896.) In addition, these processes were modified by a tilting of the reëlevated peneplain in opposite directions in the north and south (Powell, 1896, p. 79).

C. Present Condition of Drainage. (See Plate XII.)

At the present time we have only in the southern Appalachians the remnants of the primitive condition of the drainage, streams running toward the west, with their sources near or in the Blue Ridge, well to the east. This is the case in the Tennessee and New River region. New River is a good example of this, and we may safely regard this river as representing most nearly the original drainage features (Davis, 1907, p. 732: "There is not another river in the whole Appalachian region that so well preserves its ancient course.")[11]

Following the Allegheny Mountains and the Allegheny Valley northward, we meet streams draining more and more in an easterly direction, first the Roanoke, then, in succession, the James, Potomac and Susquehanna, and it is interesting to notice that the first one

[11] Davis means here by "ancient" preëminently the Pretertiary time. But probably the present New River is not the oldest line of discharge out of this region. Using the same methods as used by Davis (1889) for the construction of the old Anthracite River in Pennsylvania, we would obtain an old river running West in the depression between two elevations (monadnocks), along which now runs the Chesapeake and Ohio Railroad (between Covington and Hinton, see Pl. XII. and profile, Pl. XIV., fig. 2). Probably the fault on the western side of Peters Mountain also played a part in defining this oldest line of discharge. The present New River would then be a later (but probably also Pretertiary) feature, and would have about the same relation to the old river, as the present Susquehanna has to the old Anthracite River, after its reversion.

occupies only the valley, and very little of the mountains, while every succeeding one cuts farther back into the mountains (Campbell, 1896, p. 675).

In the region of the uppermost Roanoke there is a good instance of more recent stream piracy. The headwaters of the North Fork are running first in a southwesterly direction in a valley, which is clearly continued toward New River; but just north of Christiansburg this fork makes a sharp bend, cuts through Paris Mountain, and flows then eastward and northeastward. It is clear that the Roanoke has captured here a former tributary of New River (see Campbell, 1896, p. 674, and our map, Pl. XII., and profile pl. XIV, fig. 1).

James River has cut much farther into the Allegheny Mountains. It is doubtful whether the original streams in this region belonged to New River. According to Hayes and Campbell (1894, p. 110) no important shifting of divides has taken place in this region during the Tertiary cycle, although, as we have seen, Campbell (1896) assumes stream piracy between James and Roanoke. This region is extremely complex in structure and has little been investigated.

Coming to the Potomac drainage, we observe that this river has cut clear across the mountains, and has reached, in northeastern West Virginia and in western Maryland, the western boundary of the Allegheny Plateau, Allegheny Front, and at one point has even cut through this and encroached upon the Allegheny Plateau, draining now a longitudinal synclinal valley. (See our map, Pl. XII., and profile pl. XIV, fig. 2.) As to the former drainage in this region very little is known. But according to Campbell (see above) the Potomac has robbed, in the region of the mountains, James River, and in one case, in the Shenandoah Valley, we have instances of more recent stream piracy during the Tertiary cycle. The Shenandoah is a rather recent stream, which has captured in succession several older streams, running originally independently through Blue Ridge eastward (see Davis, 1891, p. 576, and Abbe, 1889, p. 68).

The Susquehanna in Pennsylvania has progressed farthest in the capture of western streams. It has not only cut clear across the mountains, but also has invaded a large section of the plateau, which

originally drained to the westward (see Plate XII.) The primitive drainage features of this region have been worked out by Davis (1889), and according to him this whole region was once drained by the ancient Anthracite River, running in a northwesterly direction through what is now the anthracite basin, its sources being situated well to the east, in the Kittatinny highland. The upper part of this river was first reversed, so that it discharged southeastward (direction of present Schuylkill), and then the Susquehanna encroached upon this system, becoming finally the master stream in Central Pennsylvania during Jura-Cretaceous times. The final step in the development of this drainage was the capturing of the plateau drainage, but also this falls largely into Pretertiary times. That the Susquehanna encroached also southwestward upon the drainage of the Potomac has been mentioned above, and this probably is the chief change of this system which belongs to the Tertiary time.

D. History of the Western Drainage.

At the present time all western streams are finally united into one great system, that of the Ohio, which finally runs into the Mississsippi and the Gulf of Mexico. In the past this was different, and we know now that the present system is of comparatively young age, that the Ohio is a recent stream, and that the former drainage features of this region were entirely different. According to the investigations of a number of writers (for instance, Foshay, 1890; White, 1896; Leverett, 1902; Tight, 1903), there was no Preglacial Ohio River, but in its place there was a system of northward flowing streams. In the region under consideration two of them are well established: the *Old Monongahela* in western Pennsylvania and northern West Virgina, and the *Old Kanawha* in West Virginia (the Big Sandy belonging to the latter). How the conditions were farther down is somewhat doubtful, but there might have been a third river of the same general character (Licking-Miami, or *Cincinnati River,* see below).

The advancing ice of the Glacial period shut off the outlet of these rivers, dammed them up, converted them into lakes, and finally the waters were forced to seek another outlet, and the general slope

of the country and the direction of the edge of the ice made them find this outlet in a southwesterly direction, thus connecting the old Preglacial systems by a new river, which was the beginning of the present Ohio. *The Ohio thus was formed during Glacial times.*

The northward flowing Preglacial rivers were connected by a master stream called *Erigan River,* running in a direction about parallel with the direction of the present St. Lawrence. There is some dispute as to the direction of this old river (northeast or southwest), but the evidence preponderates which assigns to it a northeasterly flow. The present writer has shown also (1906, p. 429) that certain facts in the distribution of crayfishes point to this conclusion, that is to say, that this drainage finally was eastward into the Atlantic Ocean. This question will be discussed farther below.

E. Mutual Connection of the Atlantic Streams.

The present Atlantic streams, Delaware, Susquehanna, Potomac, James, Roanoke, are quite independent from each other, and discharge separately into the sea, so that no direct intercommunication of their waters seems possible. However, we have seen that their headwaters interlock closely, and that it is probable that in the past stream capture has taken place between them in the region of the Allegheny Mountains (see above the quotation from Campbell, 1896, p. 675). In their course across the Piedmont Plateau these streams are at present generally well separated, but farther to the east, where they enter the region of the Coastal Plain, they reach a physiographical section of a character which permits frequent interchange of the waters. In addition, we know that the Coastal Plain extended, at certain times, farther seaward, and that the present Delaware and Chesapeake Bays and also the estuaries of the other Atlantic streams represent drowned river valleys, so that probably in the past this interchange of the waters took place on a larger scale (see LeConte, 1891; Powell, 1896, p. 73; Spencer, 1903; Davis, 1907, p. 717).

Thus the Atlantic streams were not always isolated from each other, and in the past, as well as in the present, an intercommunication of their waters was possible, chiefly on the Coastal Plain, which, of course, also must have permitted an exchange of the faunas. The importance of this will be understood below.

Chapter 6.

Explanation of Distributional Facts.

We are now ready to study the faunistic facts with regard to their genesis, and shall take them up according to the classification given above (Chapter 4, pp. 338–341).

Fact I., 1.

The fact that the eastern and western faunas are sharply distinct, and that the Allegheny system actually forms a sharp faunistic barrier of the freshwater faunas, does not need any comment, for mountain ranges generally are most apt to act as divides between rivers and their faunas unless the elements of these faunas have exceptional means of dispersal (by transport). The very fact that the western forms generally have not crossed the divide, nor have the eastern forms, indicates that among three of the groups discussed here (Najades, Pleuroceridæ, Crayfishes) no such exceptional means of dispersal have acted to any considerable degree. However, as we shall see farther on, there are some exceptions.

One point, however, deserves special mention. There have been periods of general base-leveling, the last important one belonging to the Cretaceous time. It is very likely that at this time the barrier was not so well marked, and that a more general interchange of the faunas was possible. If any cases in the present distribution are to be traced back to this time, there are very few of them, and the majority of the cases, chiefly of the *Najades*, does not show any evidence of this. This means to say that probably the bulk of the *Najad*-fauna of the Appalachian River systems *is not older than the Cretaceous time, probably largely Postcretaceous.*

This is an important conclusion in view of the fact that we know from fossil remains that *Najades* existed in North America in Jurassic time and possibly even earlier. But it should be noted that these fossils are known practically exclusively from the western parts of the continent. This, however, cannot be followed up any farther, since it would lead us too far away from our present purpose.

While thus the western fauna could not cross the Alleghenian

barrier, we further have noticed the fact that it forms distinctly a unit from the upper Allegheny River at least to Licking River in Kentucky. It is hardly necessary to discuss this, since the present conditions sufficiently explain this uniformity; all these rivers, running westward, are united into one master stream, the Ohio. Also the system of the Tennessee, which has much in common with the Ohio, finally unites with this river.

However, when we come to study the origin of this fauna and to consider the fact that the Ohio drainage in its present form is a modern feature of our hydrography, we have to ask the question, what the old conditions were?

There is hardly any doubt that the uniform *Najad*-fauna of the upper Ohio basin is, in its origin, connected with the origin of the Ohio River, that is to say, that it is not older than the Glacial time, probably largely Postglacial. The fact brought out above, that from the upper Allegheny downstream this fauna becomes richer, and that the number of species increases steadily farther down (from 47 in Pennsylvania to about 60 or more in the vicinity of Cincinnati), makes it certain that the center of dispersal of this fauna was in the region of the lower Ohio, probably also including the Tennessee system, and that *this fauna migrated upstream in Glacial and Postglacial times* as soon as the present Ohio was formed, depauperating gradually in the direction toward the headwaters.

Fact I., 2, (a).

The fauna of the upper Tennessee is very strongly marked. Nevertheless it shows distinct affinities to the Ohio fauna. We have studied only a very small part of it, and it is well known that farther down in the Tennessee and also in the Cumberland River drainage, this fauna becomes still richer.

Without a closer and more exhausting study of this fauna it is impossible to express any definite ideas as to the origin of it. Thus we have to dismiss this topic here and it is sufficient to say that probably this fauna represents the common ancient stock, and the great center of radiation, not only of the interior basin fauna, but also of that of the Atlantic slope and the Gulf region. That the Ohio

River fauna probably is a branch of this fauna has been indicated, and the migration was in this case from the lower Ohio upstream. The question remains whether the upper Ohio received also elements from the upper Tennessee by another route, and this question is suggested by the fact that the headwaters of Clinch and Holston rivers on the one side and those of Big Sandy and New River approach each other very closely and frequently interlock in the mountains.

It is known (see Campbell, 1896, p. 670) that the headwaters of the Big Sandy are preparing to capture the headwaters of Clinch River in Tazewell Co., Va., in a region where the latter river has a rich and characteristic fauna. The Big Sandy tributaries have already reached the valley limestone and may have already deflected some of the smaller tributaries of the Clinch. In the *Najad*-fauna of the Big Sandy (see p. 309) there is no evidence for this. But the fact that a species of *Pleurocera, Pl. unciale,* is common to the Clinch and the Big Sandy, possibly supports this assumption.

There is also little evidence for a communication between the upper Tennessee and New River except the existence of the *Pleurocerid*-genus *Anculosa* in both systems and the presence of an identical species of crayfish, *Cambarus longulus.* The two species of *Najades,* which are common to both systems, *Elliptio dilatatus* and *Alasmidonta marginata,* are without convincing value, since they are found all over the interior basin, and of *Elliptio dilatatus* there is surely quite a different, dwarfed race in the New River, while the Clinch contains the normal form. In view of the tremendous contrast between the upper Tennessee and the New River faunas, it is not very likely that there was any extended migration at any time across this divide, or that there was any important shifting of this divide. This is in accord with the general history of these streams. According to Campbell (1894, p. 110), the divide between New and Holston rivers is a narrow col characteristic for a long-maintained divide, and Hayes (1896, p. 330) says that the headwaters of the Tennessee, running generally over softer rocks, had a tendency to encroach northeastward upon the upper Kanawha system, but that this tendency was counterbalanced by the fact that New River also cut its own channel deeply into the (harder) rocks of its own trans-

verse valley. If there was any stream piracy in the past it would have been the Tennessee, which had the advantage over the New River, so that the latter could not receive anything from the former.

This seems to be supported by the general character of the fauna. The two cases mentioned above (*Anculosa* and *Cambarus longulus*) will be taken up again further below.

Fact I., 2, (b).

The main fauna of the Ohio reaches, as we have seen, in the Kanawha and the mountain tributaries of the Monongahela only up to the lower end of the falls-line, marked by a canyon. It is clear that here the upward migration of the Ohio fauna is checked by the physiographical character of these streams. The upper Allegheny and its tributaries are Plateau streams, originating upon the Allegheny Plateau at elevations of about 2,000 feet (see pl. XIII, fig. 1), and the West Fork River of the Monongahela falls into the same class (see pl. XIII, fig. 2), and in these streams the fauna goes way up. But in the case of the tributaries of the Monongahela, Youghiogheny, Cheat, Tygart, and also in New River (including Greenbrier) of the Kanawha system, the sources are in mountains of 3,000 to over 4,000 feet elevation. These rivers have a very steep grade, and in a certain region they all run through a more or less well developed canyon. The lower end of this canyon forms the upper boundary of the Ohio River fauna in the Youghiogheny at Connelsville, Pa., in the Cheat at Mont Chateau, W. Va., in the Tygart at Grafton, W. Va., in the New River at Kanawha Falls, W. Va.[12] (Compare our profiles, Pl. XIII., fig. 2, and Pl. XIV., fig. 1.)

We have to regard it as an ecological fact among the *Najades* (and some other freshwater Mollusks, for instance, the genus *Pleurocera*), as well as in the river-crayfishes (Ortmann, 1906, p. 412), that they do not like rough water and unstable, shifting bottom. The canyons of the falls-line of these rivers are, next to their upper-

[12] Of course, exceptional cases, where single species have found a way up and through the canyon, may be disregarded. Such are the cases of *Quadrula tuberculata* and *Rotundaria tuberculata* in the New River at Hinton, and probably also of *Symphynota costata* in the Tygart at Elkins.

most headwaters, the roughest parts of them, characterized by firm bedrock bottom covered with loose stones and boulders, often shifting, chiefly during flood stages. Such conditions are entirely unfavorable to crayfishes and *Najades* (the latter generally demanding sand and gravel, which is *firmly packed*), and thus we have here an *ecological barrier to the upstream migration of the Ohio fauna*, which is absent, for instance, in the upper Allegheny.

The fact that this fauna is here checked by a *modern* physiographical feature confirms the assumption that the upstream migration of it falls in a rather recent (Glacial and Postglacial) time.

Excepting these mountain streams just discussed, the uniform Postglacial upper Ohio fauna comprises all the headwaters of the Ohio (Allegheny and Monongahela), and further all the tributaries in West Virginia; also the fauna of the Big Sandy belongs undoubtedly here, and we know that this river once was closely connected with the Old Kanawha River (Tight, 1903), and that its history was similar to that of the other rivers, which are ancestral to the upper Ohio system. This is somewhat different in the case of Licking River in Kentucky. Leverett (1902, p. 109) unites this river with the Preglacial lower Ohio (and with the Kentucky, Cumberland and Tennessee rivers). If this is correct, we should expect in this river the Tennessee-Cumberland fauna; but there is no trace of it here,[13] and the Licking fauna is entirely of the same character as that of the rest of the upper Ohio, as far as it concerns the *Najades*. Of *Pleuroceridæ* a new species turns up here, but this material is too unsatisfactory. But on the other hand a peculiar crayfish is found in the Licking, *Cambarus rusticus*, which distinctly points to the west. But since also Monongahela and Kanawha are characterized by different (although closely allied) species of crayfishes, Licking River also in this particular falls in line with these other streams.

The physiographical evidence with regard to the history of Lick-

[13] See p. 309. The fauna is not completely known, but according to my collections, only one species turns up, which is absent in other parts of the upper Ohio drainage discussed here: *Anodontoides ferussacianus*. All the rest is typically upper Ohioan. It also should be noted, that one species, *Lampsilis luteola*, is present here, which is absent in the Cumberland-Tennessee fauna.

ing River is yet obscure. As we have seen, Leverett unites it with the Preglacial lower Ohio. But the fauna of the river, especially of the *Najades,* strongly points to the fact that Licking River has a similar history to that of the Kanawha and Monongahela, that is to say, *that it was in Preglacial times a northward flowing stream, which might have belonged to the old Erigan River* (see above, p. 349), and that it had no connection with the lower Ohio and Tennessee-Cumberland. And indeed this is the assumption made by Tight (1903, see map, pl. 1), who gives to the Licking and Kentucky rivers (under the name of *Cincinnati River*) a northward flow in Preglacial times.

Thus, in this case, zoögeographical evidence is in favor of Tight's assumption, and this is an interesting instance, where zoögeography contributes to the solution of a physiographical question.[14]

We have repeatedly emphasized, that the upper Ohio fauna is a unit, and rather uniform all over the terrritory it occupies, with the only qualification, that it slowly depauperates in an upstream direction. This is true, in the first line, of the *Najades,* but it may be correct also for certain *Pleuroceridæ,* at least such forms which follow mainly the large rivers (certain species of *Pleurocera,* as for instance, *Pl. canaliculatum*). But in other groups, some minor differences within the upper Ohio fauna are noticed. Some evidence of this is seen in the *Pleuroceridae* of the smaller rivers, the Allegheny, Monongahela, Kanawha, Big Sandy and Licking, each of which has different species of *Pleurocera* and *Goniobasis* (provided such are present at all). But these conditions require further study, chiefly with regard to the affinities of these forms. But it is interesting to note, that it seems that the conditions known to exist among the crayfishes are duplicated here.

In the case of the crayfishes, I have pointed out (1906), that there are two different species in the upper Ohio drainage, and that

[14] This should be studied farther, chiefly with regard to the additional question regarding Kentucky River: If Tight's and our view is correct, Kentucky River should conform in its fauna to that of Licking River and the upper Ohio in general; if it belongs, however, to the lower Ohio, it should contain elements of the Cumberlandian fauna. Unfortunately the Kentucky fauna is practically unknown.

their distribution undoubtedly is *correlated with the old Preglacial drainage systems. Cambarus obscurus* belongs to the old Monongahela River, while *C. propinquus sanborni* indicates, in its present distribution, the old Kanawha River. This theory has been fully confirmed by my subsequent investigations, which have shown that *C. obscurus* actually is the river-species of the Monongahela in West Virginia, up to the headwaters of the Plateau stream West Fork River, while to the south of this, in the little Kanawha, Big Kanawha, Guyandot, and in the corresponding part of the Ohio proper, *C. propinquus sanborni* is found. This latter form probably is also in the Big Sandy, and a few smaller streams to the west of this in Kentucky, all belonging to the Old Kanawha of Preglacial times.

The additional information was obtained that in Licking River another species is found, *C. rusticus*. This means, that this river had a more isolated position from the others in Preglacial times, although belonging probably also to the old Erigan drainage.

While thus the *Najad fauna* of the upper Ohio follows in its distribution the modern features of this river, and while we are to conclude, for this reason, that it is largely *Postglacial*, the *crayfish fauna* indicates *Preglacial* conditions. And further, it seems that, among the *Pleuroceridæ*, we have both elements represented, but, unfortunately, the natural affinities of this group are yet too obscure to permit any final conclusions.

Fact I., 2, (c).

In the headwaters region of the mountain streams tributary to the Monongahela and Kanawha, above the canyon, there is generally a section, where these rivers are less rough, and run more quietly in elevated, often broad valleys (compare profiles, Pl. XIII., fig. 2, pl. XIV., fig. 1). As has been said, the fauna of these parts is chiefly characterized by the *absence* of the common upper Ohio types. Nevertheless we have a small number of forms here, which are more or less characteristic.

These forms are not uniformly present in all these rivers, and their distribution may be tabulated as follows:

1. Monongahela drainage—

a. Youghiogheny: *Strophitus edentulus.*

b. Cheat: *Anculosa dilatata.*

c. Tygart: *Symphynota costata, Strophitus edentulus, Anculosa dilatata.*

2. Kanawha drainage—

a. Greenbrier: *Elliptio dilatatus, Symphynota tappaniana, Alasmidonta marginata, Anculosa dilatata, Cambarus longulus.*

b. New River: The same as in Greenbrier, and in addition (at Hinton only): *Quadrula tuberculata* and *Rotundaria tuberculata.*

Two classes may be distinguished among these: those which have no relations on the eastern side, and those which are represented there by identical or very closely related forms. The former are: *Symphynota costata* of the Tygart, and *Quadrula tuberculata, Rotundaria tuberculata, Elliptio dilatatus,* and *Alasmidonta marginata* of the upper Kanawha. These are species rather generally distributed in the upper Ohio region, and they probably belong to this fauna, representing forms, which for certain special reasons, possibly by mere chance, were able to ascend somewhat higher in the mountain streams than the bulk of the Ohio fauna.

The other forms, *Symphynota tappaniana, Strophitus edentulus,* and the crayfish *Cambarus longulus,* are represented on either side of the divide by the identical species, while in the case of *Anculosa* two extremely closely allied species, *A. dilatata* and *carinata,* are found west and east of the divide.

These latter facts are very interesting, and touch upon the question, whether and how it was possible that certain forms of freshwater life were able to cross the divide. For the present, we shall only indicate this problem, but we shall take it up again, when we come to speak of the Atlantic forms, which are more or less nearly related to western ones (see below, under fact II., 2, *c*).

It also should be pointed out, that an additional interesting question is involved here. We have seen, that the general Najad-fauna of the Ohio, which goes up to the lower end of the canyons, is of Postglacial age. This fact suggests, that also the falls line of the canyons is comparatively recent, and that it marks a last rejuvena-

tion of these streams in consequence of a reëlevation of the country. According to Foshay (1890, p. 400) and others, this rejuvenation is of Postglacial age. *Thus we might expect to find in these upper parts of the mountain streams, the remnants of the fauna which existed in these rivers in Preglacial (Tertiary) times.* I have no doubt, that at least some of these are Tertiary elements, and possibly just those which are found on either side of the mountains might belong to them. However, this fauna is too fragmentary, to be sure about this, and it is quite evident, that also in Tertiary times not the whole of the fauna of these rivers went up to near the headwaters. Thus we have to wait till additional evidence with regard to the Tertiary fauna of the headwaters of the Erigan system is forthcoming.[15]

Fact II., 1, (a).

It has been seen, that there is a certain amount of uniformity in the Atlantic fauna, in spite of the fact that the Atlantic river systems are quite isolated from each other. In fact, most of the Atlantic species are not restricted to a single drainage, but are found in several, often practically in all of them. This means, that there is or there was the possibility of an intercommunication of the faunas of these rivers, and the question arises, how this was brought about.

All these rivers, after having traversed the Piedmont Plateau, run for a greater or lesser distance through the Coastal Plain. This plain is little elevated above sea-level, and consequently the rivers are sluggish here; there is considerable deposition of material in this region, and a great tendency toward a change in the river channels: the rivers are practically at base-level. It is a general rule, that in a country approaching base-level, the intercommunication of neighboring rivers is greatly facilitated (see Adams, 1901, p. 842), and that consequently a wide distribution of the fauna is favored.

[15] The best evidence would be fossil forms from the high river terraces. Such do exist, but the remnants are too poorly preserved, to be of any value. It should also be noticed, that there is a number of species in the upper Ohio drainage, which distinctly avoid the larger rivers: also these might be elements of the old Tertiary fauna. It is interesting, that several species of the present fauna of the mountain streams fall into this class, namely: *Symphynota costata, Alasmidonta marginata, Strophitus edentulus.*

There is no question that this is one of the factors, which has largely brought about the more or less universal distribution of the species of the Atlantic slope, and has permitted their spreading from one river system into others, notwithstanding the contrary opinion of Johnson (1905), who does not believe that "river captures" are to be assumed in this region, but that passive transportation accounts for the universal distribution of certain Najades over the Atlantic slope. Indeed, it is not river capture in the strict sense, which caused the present conditions, but what Adams (*l. c.*) calls "removal of barriers" in a country approaching base-level. This is also practically the opinion of Simpson (1893, p. 354, footnote 2), when he says, that shells may migrate from river to river "across overflowed regions near the sea, in times of floods." (We always must bear in mind that the migration was by the help of fish, which carried the larvæ.)

This lowland zone reaches all the way up the coast to New York state. But we know, that at certain times it extended even farther north, when the continent stood at a higher elevation, and when the coastal plain was wider than at present. We must also consider, that at other times the coast was more submerged than now, and that then also the Piedmont Plateau was more or less at base-level, offering the same conditions favorable to a migration of the fauna.

Moreover, we have seen, that there was stream-capture in the region of the mountains, and that the northern rivers had a tendency to encroach upon the southern. This should have caused a migration of southern forms northward in the mountain region, but not of northern forms southward. There is indeed evidence of it in the fact, that forms with a northern center of dispersal (those falling under II., 2, *b*) availed themselves, in their southern dispersal, of the coastal route, for instance, *Lampsilis radiata, cariosa, ochracea* and *Cambarus limosus,* for they become more and more restricted to the lowlands in the southern parts of their range. On the other hand, those forms, which have a more general distribution, also in the mountain region, are chiefly southern in their origin, as for instance: *Elliptio complanatus, Alasmidonta undulata, Goniobasis virginica,* and these may have availed themselves, in their

northward dispersal, also of stream piracy in the mountains. In a few cases, the latter probably was the prime factor in the dispersal, chiefly in the case of *Anculosa carinata*.

Thus there is no difficulty in admitting the possibility of the dispersal of the Atlantic fauna over more or less of the whole region. The facts in the distribution of the *Najades*, as well as in the *Pleuroceridæ*, and in the *crayfishes* support this assumption. But the other fact, that certain forms of the Atlantic slope did not reach a universal distribution, and were apparently obstructed in their dispersal at certain points, needs further discussion. This is a more difficult problem, but, as far as possible, it will be taken up below.

FACT II., 1, (b).

Aside from certain species (Najades: *Elliptio fisherianus*, *Anodonta cataracta* and *implicata*, *Eurynia nasuta*, *Lampsilis radiata*, *cariosa*, *ochracea*, and the crayfish *Cambarus blandingi*), which are more or less typically species of the lowlands or the great rivers, the fauna of the Atlantic streams is rather uniform, in each system, from the Piedmont Plateau upward into the mountains, to near the sources. (See list no. 23 of Najades, and also *Goniobasis virginica*, *Anculosa carinata*, *Cambarus limosus*.) That is to say, the fauna does not deteriorate, or very little so, in an upstream direction. This differs strikingly from the conditions on the western side, where a gradual decrease of the number of species toward the sources is the rule, or where we even observe a sudden disappearance of species at certain points in the mountain streams.

The explanation of this fact is found, as I believe, in a general physiographical character of the Atlantic streams, which is best expressed by their profile (see our profiles on Pl. XIII., and Pl. XIV., fig. 1). We see that the profiles of the Atlantic streams are more nearly normal (Abbe, 1899, p. 61, fig 3; of course we must disregard the falls line at the eastern edge of the Piedmont Plateau). This profile indicates comparative stability, with the slope steepest at the headwaters, decreasing rapidly just below headwaters, and then gently farther down. These streams are more mature than those of the western side. On the eastern side, new cycles of ero-

sion, of rejuvenation, indicated by falls or rapids beginning somewhere in the lower parts, have had time to work back to the headwaters (the cycle being completed), while on the western side these cycles, at least some of them, are not quite finished, and are indicated by falls and rapids lying at various distances below the headwaters (see profiles, Pl. XIII., fig. 2, Pl. XIV., fig. 1).

It does not require any further discussion to see that this difference of the eastern and western streams is finally to be referred to the different general slope of the rivers, the former being short and more direct in their course to the sea, and thus working faster.

The consequence is, that the aquatic life of the lower sections of the Atlantic streams finds congenial conditions up to near the headwaters, since the conditions are more nearly uniform all along the stream. Only close to the headwaters, there is a rather sudden change, and here the fauna deteriorates also quite suddenly.

Fact II., 2, (a).

We have seen that a *differentiation of elements* within the Atlantic fauna is indicated, and that first of all, a *southern element* is clearly distinguishable. A number of *Najades* belong here, the snail *Goniobasis virginica,* and two crayfishes, *Cambarus blandingi* and *acuminatus* (see p. 340).

In all these forms it is evident that they have their center of radiation somewhere in the southern section of the Atlantic slope (Carolinas, Georgia), whence they migrated northward (see Simpson, 1896*b*, p. 337). But we notice that the different forms have advanced northward to different points. Some of them spread all over the Atlantic slope, northward even beyond the section discussed here; so, for instance, *Elliptio complanatus, Alasmidonta undulata* (possibly also *Alasmidonta heterodon*), which go to New England; *Goniobasis virginica* has reached the state of New York, and *Cambarus blandingi* (restricted to the lowlands) has reached middle New Jersey.

Others do not go so far. *Elliptio fisherianus,* a lowland form, goes northward to the lower Delaware; *Elliptio productus* to the Potomac; *Elliptio lanceolatus* and *Cambarus acuminatus* to the

Rappahannock; *Lexingtonia subplana, Alasmidonta collina, Eurynia constricta* to the James; and *Goniobasis symmetrica* to the Roanoke.

This peculiar fact, that the southern elements in the Atlantic fauna have advanced to different distances northward, is hard to explain. The general tendency to migrate northward is understood by what has been said under II., 1, *a*, but the question remains, why certain forms have been unable to go as far as others.

In part, I believe, this may be explained by the ecological preferences of the single species, and a comparison of a few of them will show what I mean. *Elliptio complanatus* is ubiquitous, and is able to live under a great variety of environmental conditions. It consequently had the best chance to spread north, and actually has the widest range of all. *Elliptio fisherianus* is a typical lowland species, and it has used the easy way over the coastal plain, and has succeeded in going farther north than the two allied species, *E. productus* and *lanceolatus*, which, as far as I can judge, are rather upland species, which could not avail themselves so much of the opportunities offered by the lowlands; they very likely depended more on stream capture within the mountains, which naturally was a slower and more difficult way of dispersal. Probably this holds good also in the cases of *Cambarus blandingi* and *C. acuminatus;* the former is a lowland species and has reached farther north than the latter, which seems to be an upland species.

This, however, is only a suggestion. Our knowledge of the actual distribution, and also of the ecological habits of these forms is not satisfactory enough to draw positive conclusions.

It is also possible, that the special history of these forms, chiefly with regard to their geological age, plays a part in this, and it might be that the oldest forms had the best chance to obtain the widest range. This might be correct in the case of *Elliptio complanatus*, while a rather recent type, *Eurynia constricta*, has stopped rather far south. But this surely is no general explanation, as is seen in the case of *Lexingtonia subplana*, a primitive type, which did not go farther north than *Eurynia constricta*.

This question should be taken up in connection with a more detailed study of the origin and the distribution of the southern At-

lantic element, and this is a problem correlated with the Tennessee-Coosa problem, and the connection of the Tennessee fauna with the southern and southeastern drainage systems of the Appalachians. It can be solved only after much more extended investigations in the Gulf and Atlantic streams from Alabama to the Carolinas.

This much is sure, that the existence of this southern element in the Atlantic fauna is well established. Simpson (1893, p. 355) already has indicated it clearly, and that it probably is connected with the fauna of the interior basin around the southern extremity of the Appalachians (see also Ortmann, 1905, p. 124). This center forms part of Adams' (1902 and 1905) great southeastern center, but is probably a rather sharply separated, and rather old subdivision of it. It had, with regard to aquatic life, a northward route of dispersal, not only in Postglacial, but also in Preglacial times, on the Atlantic slope. This route has been admitted by Adams (1905) for land-forms, but has not been mentioned (*l. c.*, p. 63) for aquatic forms.

Fact II., 2, (b).

Another element of the Atlantic fauna seems to have its center in the *north* (from Pennsylvania and New Jersey northward). The following *Najades* belong here: *Anodonta cataracta, Anodonta implicata, Alasmidonta varicosa, Lampsilis radiata, Lampsilis cariosa, Lampsilis ochracea*,[16] and the crayfish: *Cambarus limosus*. All these forms have in common, that they are most abundant northward, and advance southward either not at all (*Anodonta implicata*), or chiefly on the coastal plain. Only *Alasmidonta varicosa* seems to be more universal in its distribution on the Atlantic side. *Lampsilis ochracea* is a form of the lowlands (estuaries). *Lampsilis radiata* and *cariosa*, and apparently also *Anodonta cataracta* have a rather wide distribution in Pennsylvania, but southward they seem to occupy only a narrow belt on the coastal plain. The same is true of *Cambarus limosus*. However, our knowledge of the distribution of these forms in the lowlands of Virginia, and southward, is rather unsatisfactory, but the fact is undeniable that, while these

[16] *Margaritana margaritifera* and *Eurynia nasuta* resemble these to a degree, but, as we shall see below, are peculiar in other respects.

latter three forms are found in Pennsylvania way up into the mountain region in the Susquehanna, they are missing west of Blue Ridge in the Potomac,[17] James, and Roanoke. This fact, that the southward range of some of these forms falls largely within the coastal plain, where there were special advantages for migration, is corroborative evidence for their northern origin: they were first and originally present in the northern section of the Atlantic slope, where they had, in consequence of the longer time elapsed, a better chance to spread upstream.

I have treated of the origin of the distribution of a member of this northern fauna, *Cambarus limosus,* in a former publication (Ortmann, 1906, p. 428 ff.). I have pointed out, that this species is well marked, but possesses allied forms in the interior basin, and I have not the slightest doubt that the *Najades* enumerated above fall under the same head, and that the origin of their distribution is to be explained in a similar way. Also these *Najades* are well defined species, but possess allied representatives in the interior basin (see above p. 325).

According to the theory advanced for *Cambarus limosus,* these *Najades* came around the northern end of the Appalachians, in Preglacial times, by way of the Erigan River, which flew in the general direction of the present St. Lawrence. This river received the ancestral forms of these species from the interior basin (more especially from the lower Ohio and Tennessee drainage) in some way, which is at present not fully understood. But there is no serious obstacle to the assumption of this possibility on account of the probable numerous changes of the drainage in these parts. Having once reached the Atlantic coastal plain at the mouth of the Erigan River (region of St. Lawrence Gulf and New Foundland), there was no barrier to their farther dispersal southward, chiefly since the coastal plain, as we know, extended at certain times further seaward. This dispersal was first along the coast, but several of these forms migrated thence upstream in the various rivers of the Atlantic side.

[17] *C. limosus* is found here and there in the upper Potomac, but it probably reached these parts only recently by the aid of the Chesapeake-Ohio Canal.

The southward migration was unequal, but the causes of this are not very clear, but might be compared with the similar phenomenon in the case of the southern elements.

When the Glacial period set in, the ice coming from the north separated the eastern range of these forms from that on the western side. Habitudinal segregation was thus effected, and this induced differentiation into species. The final consequence is, that the Atlantic forms developed into well marked species, which have a rather young age (Glacial), and still are closely allied to corresponding forms in the interior basin. In Postglacial times, after the ice had disappeared, a reaction, a northward migration set in, and these species reoccupied a good deal of the territory lost in Glacial times. In this advance they were accompanied by certain southern types, which also invaded the glaciated area (*Elliptio complanatus, Alasmidonta undulata*).

Thus the origin and the history of this part of the Atlantic fauna appears rather clear. The most interesting fact is, that the case of *Cambarus limosus* has a number of parallel cases among the *Najades.* This element in the Atlantic Najad-fauna, however, has been recognized already by Simpson (1896*b*, p. 337), who also explains its origin by migration around the northern end of the Appalachians.

Considering the two elements together, the northern and the southern, and the fact that the species belonging to them migrated to various extents south or north, we obtain a satisfactory explanation of the fact, mentioned above (p. 315, 318), that the Susquehanna, and also the Potomac, fall short, in the number of species, of the rivers both to the north (Delaware) and south (James). Certain forms of the northern fauna have not gone south beyond the Delaware, and certain southern forms have not gone north beyond the James, and this leaves a balance against the intermediate systems of the Susquehanna and Potomac. In the Susquehanna, this shortcoming has been in part supplemented by an indigenous form (*Alasmidonta marginata susquehannæ*), and in the Potomac by a southern form (*Elliptio productus*). This peculiar condition is a point which very strongly speaks for our assumption of two distributional centers in the Atlantic fauna, a northern and a southern.

FACT II., 2, (c)

There is a third group of forms among the Atlantic fauna, which have for a common character the fact that they are *conspecific or extremely closely allied to western forms*, and which show in their distribution certain peculiar, but not quite uniform conditions. We have seen (under I., 2, *c*, p. 339, 357) that the corresponding western forms are in part characteristic for the mountain streams tributary to the Monongahela and Kanawha, so that there is the appearance, as if certain species had crossed the divide of the Allegheny Mountains. It remains to be investigated, whether such a crossing of the divide should be admitted, and what the means were, by which this was accomplished.

Certain cases, however, should be dismissed[18] from the beginning, namely first of all those, where passive migration by *transport* is probable or possible. The *Sphaeriidæ* belong here, and also *Campeloma decisum*. Here the whole character of the distribution is such, that it does not appear to follow drainage systems at all, but goes across country, suggesting exceptional means of dispersal, such as transportation by birds etc.

In other cases, *active migration* across divides is possible and probable: this concerns chiefly, as I have pointed out in a previous paper (Ortmann, 1906, p. 448), the crayfish *Cambarus bartoni*. This species, as well as the *Sphæriididæ* and *Campeloma decisum*, has a rather universal distribution east and west of the divide.

And further, I shall disregard here *Cambarus spinosus* and *acuminatus*, as belonging to the southern Appalachians, as far as it concerns the distribution on both sides of the divide, and also *Eurynia constricta* and *vanuxemensis* fall into the same class.

Thus there remain the following forms to be discussed here.

1. *Strophitus edentulus*.
2. *Alasmidonta marginata* and *marg. susquehannae*.
3. *Symphynota tappaniana*.

[18] Two very recent cases, *Cambarus obscurus* and *Lampsilis ventricosa* (*cohongoronta*), in the upper Potomac must be entirely disregarded, for here artificial, although accidental and unintentional, transplantation has been effected by human agency (see Ortmann, 1912*b*).

4. *Anculosa dilatata* and *carinata*.
5. *Cambarus longulus*.

The peculiarities of distribution in each of these cases have been shortly characterized above (p. 357) for the western side of the mountains, and it will be remembered that none of them are fully alike in all particulars, although resembling each other to a degree. This is also so on the eastern side. Thus it is best to take them up one by one.

Strophitus edentulus.

This species has a rather general distribution, but it is peculiar in so far as it is one of the two species of Najades which alone are found in the mountain-tributaries of the Monongahela (Youghiogheny and Tygart), while it is missing in the upper Kanawha region.[19] This forbids it to place this species simply with those which (like the *Sphæriidæ* and *Campeloma decisum*) have a universal distribution east and west of the divide. Indeed, the general distribution of *Strophitus*, for instance in Pennsylvania, might suggest that this form has exceptional means of dispersal, and might be transported from one drainage into another.[20] But its absence in the New River system speaks against this, for we cannot imagine that any means (birds for instance), which would have been able to carry this species across divides, should have carefully avoided the New River system.

Strophitus edentulus is a form eminently characteristic for small streams, and is rare or missing in large rivers. In the upper Alle-

[19] This negative statement might be doubted. But at the four localities, where I collected Najades (Ronceverte in Greenbrier River; Hinton and Pearisburg in New River; Wytheville in Reed Creek), shells were abundant, and in every case *I hunted for this species*, examining carefully also dead shells lying around; but no trace of *Strophitus* was discovered.

[20] In order to bring out all facts, which possibly might have a bearing upon this question, it should be mentioned, that Lefevre and Curtis (Science, 33, 1911, p. 863, and *Bull. Bur. Fish.*, 30 (for 1910). 1912, p. 171) have recently discovered a remarkable circumstance in the life-history of this species, different from all other known Najades: the larvae (glochidia) of *Strophitus* undergo their metamorphosis without a parasitic stage on fishes. For the present, however, I could not tell how this could favor passive transport of the young shell. But the fact should be kept in mind.

gheny drainage it goes way up into the headwaters:[21] it is in the upper Youghiogheny and in the upper Tygart and Buckhannon rivers. Thus it closely approaches the divide in the whole northern section of the upper Ohio drainage. On the eastern side, it is also found close up to the divide in the Susquehanna, Potomac, James, and Roanoke drainages.[22] The eastern and western ranges are consequently in rather close contact along the northern part of the Alleghenian divide, from the uppermost Allegheny River to the region of the headwaters of the Monongahela, Potomac and James. But the close approach is most marked in central Pennsylvania, in Cambria, Indiana, and Westmoreland counties. Here this species is common in all small streams running east and west from the divide, and, for instance, the locality in Cush-Cushion Creek, belonging to the Susquehanna, is not more than twenty or twenty-five miles from the nearest localities in the Allegheny drainage (Creekside, Homer, Goodville).

This is just in the region where the Susquehanna drainage has largely encroached upon the drainage of the Allegheny River, and where stream capture has taken place. Although Davis (1889, p. 248) believes that this was accomplished chiefly in Pretertiary times, there is no objection to the assumption that to a lesser degree this process continued in the headwaters also during the Tertiary, in fact, that it is going on at present. If this is admitted, there is no difficulty in imagining that with the waters part of the fauna of the western streams was taken over into the eastern drainage, and since *Strophitus* inhabits these smaller western streams, it might thus have crossed the divide, in this region, *by the help of stream capture.*

[21] Potato Cr., Smethport, McKean Co.; Little Mahoning Cr., Goodville, Indiana Co.; Crooked Cr., Creekside, Indiana Co.; Yellow Cr., Homer, Indiana Co.; Blacklegs Cr., Saltsburg, Indiana Co.; Beaver Run, Delmont, Westmoreland Co.; Loyalhanna Riv., Ligonier, Westmoreland Co.; Quemahoning Cr., Stanton's Mill, Somerset Co.; all in Pa.

[22] For instance: in the system of the Susquehanna: Cush-Cushion Cr., Greene Twp., Indiana Co.; Chest Cr., Patton, Cambria Co.; Swartz Run, Ashville, Cambria Co.; Beaver Dam Cr., Flinton, Cambria Co.; Raystown Branch Juniata Riv., Everett and Mt. Dallas, Bedford Co.; all in Pa.; South Branch Potomac Riv., Romney, Hampshire Co., W. Va.; James drainage: Calf Pasture Riv., Goshen, Rockbridge Co., Va.; Roanoke drainage: Mason Cr., Salem, Roanoke Co., Va.

Of course, this presupposes that the original home of this form was in the interior drainage basin. But I hardly think that this could have been otherwise, on account of the tremenduous range of *Strophitus edentulus* in the west, and we have seen that the Atlantic slope probably never has been an important center of development. *Strophitus* differs from all the other elements of the Atlantic fauna (discussed so far) by the fact that the identical species is found on either side of the mountains. Thus it is improbable that it had a similar history to that of the other forms (the northern and southern elements) of the Atlantic fauna, and we are forced to assume a special explanation of its distribution. I think, that the evidence introduced above favors the theory, that it actually crossed the divide by the help of stream capture, or in other words, by the shifting of the divide, and that this probably took place in the region of the headwaters of the West Branch Susquehanna. It might have happened elsewhere; it might have happened repeatedly: but the region indicated is the most likely. After having once (or repeatedly) crossed, this species spread over the Atlantic slope, both north and south, and occupies now the whole of it, from Virginia to New England (exact data from Virginia southward are lacking). This of course, was accomplished by the same means as in the other members of the Atlantic fauna, and it is not astonishing since this species is not only upon the Piedmont Plateau, but also on the Coastal Plain.[23]

Further details cannot be given, and chiefly it is impossible to fix the geological time when *Strophitus* crossed the mountains. As has been said, possibly this happened repeatedly, presumably in the Tertiary, and may have happened even later.[24] More information as to its southern range may furnish additional evidence, and confirm the view that the crossing of the divide was effected in the northern section of the Alleghenies, and not in the south. At pres-

[23] I found it in Delaware River, Penns Manor, Bucks Co., Pa. Its distribution upon the Coastal Plain is yet incompletely known, but it seems to be represented there at least by a local (or ecological?) form, *Strophitus undulatus*.

[24] At present, this species has a continuous range from West to East in the state of New York, and this, of course, belongs to the Postglacial time.

ent, the absence of it in the New River system is the most important fact which speaks for the assumption made above.

Alasmidonta marginata and Alasmidonta marginata susquehannæ.

The typical western *Alasmidonta marginata* has a wide distribution in the interior basin, and in the Allegheny Mountains it goes up into the headwaters of the Holston, Clinch, into New River, and into the uppermost Allegheny River, but it is not found in the headwaters of the mountain-tributaries of the Monongahela (although it is immediately below the canyon in the Cheat). In the upper Allegheny, it goes, like *Strophitus,* into very small streams,[25] and it is in general a species characteristic for smaller streams, avoiding large rivers.

On the Atlantic side, it is represented by two forms. The one is *Alasmidonta varicosa,* a closely allied, but nevertheless sharply distinct species, which has been discussed above (p. 363 f.) together with those forms constituting the northern element in the Atlantic fauna, which migrated, in Preglacial times, around the northern end of the Appalachian chain.

But there is a second representative on the Atlantic side, which has been hitherto overlooked, and which I have called *Alasmidonta marginata susquehannæ,* which stands much closer to the western form, in fact, is very hard to distinguish from it. This form is restricted to the Susquehanna drainage in Pennsylvania and New York, and it is found frequently associated with *A. varicosa,* but is always perfectly distinct from it.

It seems, according to the material at hand, that *Alasmidonta marginata susquehannæ* has its metropolis in the Juniata River and the part of the Susquehanna in central Pennsylvania, which is below the junction of the west and north branches. It has not been found in the west branch and its tributaries (although *Al. varicosa* is there), but we should consider that the fauna of this branch is poorly known, and that it has been largely destroyed by pollution from mine waters.

[25] Allegheny River, Larabee, McKean Co.; Little Mahoning Creek, Goodville, Indiana Co.; Loyalhanna River, Ligonier, Westmoreland Co.; Quemahoning Creek, Stanton's Mill, Somerset Co.; all in Pa.

In the localization of its eastern range, this form differs from *Strophitus*. But just this fact points to a connection across the divide with the western range of *Al. marginata*. This comes up, on the western side, close to the divide, and although the corresponding form is not known from the West Branch Susquehanna, the distribution on the eastern side suggests that it must have crossed the divide in this general region, presumably in consequence of stream capture. This is the more probable, since the western race of *Al. marginata* found in the headwaters of the Allegheny in Indiana, Westmoreland, and Somerset Cos., in Pa., approaches the Susquehanna-form much more closely than the typical *marginata*, as found, for instance, in the Beaver drainage.

This leads us to consider this as a parallel case to that of *Strophitus edentulus*. *Alasmidonta marginata* crossed the divide by similar means and in about the same region as *Strophitus;* but there is the difference that it did not spread beyond the Susquehanna drainage, This may be explained by the assumption that this crossing, in the case of *Alasmidonta,* falls into a later time.

Of course, this explanation is only tentative, but according to our present knowledge, it is the only possible one. The fact of the restriction of *Al. marginata susquehannæ* to the Susquehanna drainage is of the greatest weight for our argument, since we cannot imagine that this form reached its present area by any other way.

Symphynota tappaniana.

Up to shortly ago, this species was known only from the Atlantic slope, where it has a wide distribution from New England to Virginia (allied species are in North and South Carolina). On account of its relation to the western *S. compressa,* it appeared to fall into the group which has been designated as the northern element in the Atlantic fauna (indeed, Simpson, 1896*b*, places it there). But after I discovered that this species is also found in the western drainage, but only in the upper Kanawha system (Greenbrier and New rivers), where it is extremely abundant, in fact the prevailing form of Najad-life, the history of it must be different.

Its general distribution in the east, and its localization in the west, might suggest that we have here a case like that of *Alasmi-*

donta marginata, but *reversed,* and that the original range was on the east side, and that the upper Kanawha received it from the east, probably by stream capture, since transport over land is not very likely on account of the improbability that birds (or other creatures) carried this species only into the Kanawha, and refused to do so into other western streams.[26]

But as we have seen above, it is not probable that the upper Kanawha has captured any streams of the eastern drainage, but rather the reverse is true (above, p. 346 f.). The present course of New River represents most nearly the ancient drainage features, while the eastern streams (Roanoke, James and possibly also Potomac) have captured sections of the old New River and Greenbrier system. New River runs within the mountains on a distinctly higher level than most of the other streams which have cut much more deeply into the Cretaceous base-level, and thus had a better chance to capture parts of New River, than vice versa (see Pl. XIV., fig. 1).

This induces us to assume that *Symphynota tappaniana* originally was a local form of the New River drainage, developed probably out of the western *S. compressa* as an ecological mountain-form. In this case it is strange that the range of *S. compressa* does not come very near to that of *S. tappaniana,* but this may be due to a subsequent restriction of the range of *S. compressa.*[27]

[26] There is, however, one fact in favor of this assumption. *S. tappaniana* is one of the few cases of hermaphroditism known in Najades. If we grant, that in rare cases, specimens have been transported, we must admit the possibility that a new stream might have become stocked with this species, by the transplantation of a single individual. But then again, we do not know, whether self-fertilization occurs here. I mention this here, to bring out all possible arguments.

[27] The nearest place known to me for *S. compressa,* is Little Kanawha River, where it is very rare, and also this locality is isolated. Forms like *S. compressa* and *tappaniana* seem to be absent in the upper Tennessee drainage, but in the latter is *Symphynota holstonia* (which is *not* an *Alasmidonta*), and a very doubtful, incompletely known species, *S. quadrata* (Lea), which has a certain external resemblance to *S. tappaniana,* but may be anything. *S. holstonia* is surely *not* closely related to *S. tappaniana,* for it has no lateral hinge-teeth. It remains to be seen, whether there are any related forms in the upper Tennessee, which, when present, might suggest, that New River received its species from the Tennessee.

After *S. tappaniana* had reached the James drainage (it has not been found in the Roanoke, but only the headwaters of this are known), it had a chance to spread on the Atlantic side and to attain its present wide range, exactly as the majority of the Atlantic forms, favored by the same causes. It always remains a small-creek-form, but just in these small creeks the best opportunities were given to cross from one system into the other.

Anculosa dilatata and carinata.

Anculosa carinata is the Atlantic form and is known to me from the Roanoke to the Susquehanna, where it goes up into New York state. In this restriction (not being found in the Delaware and beyond) it is different from *Strophitus* and *Symphynota tappaniana,* which go to New England. West of the divide we have *Anculosa dilatata,* first of all in the same region where *Symphynota tappaniana* is found (Greenbrier and New rivers); but in addition it is also in the upper Monongahela drainage, in Tygart and Cheat rivers; in the latter it goes down below the canyon, as far as Cheat Haven, Fayette Co., Pa., and further it is found in West Fork River. Remarkably enough, it is absolutely absent in the upper Youghiogheny, although the conditions appear favorable for it.

With exception of these localities in the Monongahela drainage, the distribution fairly well agrees with that of *Symphynota tappaniana,* and we won't make a mistake if we advance the same explanation for it: stream capture on the part of certain Atlantic streams (Roanoke and James), which robbed the water and the fauna of certain parts of the old New River drainage. Thus only the presence of this form in the Tygart and Cheat needs explanation; into West Fork River it undoubtedly got from the Tygart.

The headwaters of these rivers interlock in a very complex way in Pocahontas and Randolph Cos., W. Va. (see Pl. XII.), and there is no objection on general principles to assume that there has been intercommunication of these rivers by stream capture. But conditions are rather obscure in this region and have been so little investigated from a physiographical standpoint that it is practically impossible to draw any positive conclusions as to the history of the development of the headwaters of these systems.

But it is highly interesting to notice that the distribution of *Anculosa dilatata* in the Greenbrier on one side, and in the Tygart and Cheat on the other, points to stream capture in this region, and the theory is suggested that the Monongahela drainage encroached upon and robbed the Greenbrier drainage. The opposite way is not possible on account of the limitation of this form northward, and this also speaks against the possibility of passive transport. If this assumption is correct, it also explains the fact that the Youghiogheny, which also heads in the same general region, did not receive this species. The upper Youghiogheny flows in a high synclinal valley, is more nearly an old consequent river than, for instance, the upper Cheat, which has cut down way below the level of the upper Youghiogheny. Thus it is impossible that the latter ever robbed the Cheat, capturing its fauna; rather the opposite has happened, and probably is happening now.

The Atlantic form, *Anculosa carinata,* after having reached the Roanoke and James, and after having become established on the eastern side, had the same tendency to spread as the rest of the Atlantic forms. But it did not go so far as many others, reaching only the Susquehanna drainage. In this case northward migration probably was due to the crossing over divides (by stream capture) in the mountain region. *Anculosa* is a shell characteristic for rough water in mountain streams and goes possibly farther up than any other of the forms discussed here. In the lowlands, it has never been found, and it is also less frequent in the Piedmont section of the streams, although present there. Thus its migration very likely took place chiefly within the mountains, and I think that its limited range northward is due to this fact.

The genus *Anculosa* is represented in the uppermost Tennessee drainage by the species *Anculosa gibbosa,* which is to a certain degree related to the *dilatata-carinata*-group. In fact, the Tennessee drainage is the only other region where relations of this are found. This makes it clear that New River must have received its *Anculosa*-stock from the upper Tennessee. It is hard to say how this was accomplished. We have seen (p. 352 f.) that stream capture was rare in this region; at any rate, if there was any, it was rather in the

opposite direction. Nevertheless, there might have been cases where in the headwater region smaller streams have been deflected from the Holston or Clinch to the New River, and since *Anculosa* is an abundant small-creek-type, it might thus have managed to get across. But in this case also transportation is to be considered as a possible means, since many of the headwaters originate in the same longitudinal valleys, and come very close to each other without sharp barriers between them. But the fact that the species in the two systems are sharply distinct speaks against this, for if transport had been possible once, it should have been possible repeatedly, which would have prevented specific isolation.

Cambarus longulus.

The distribution of this species again agrees, in a general way, with that of *Symphynota tappaniana* and of *Anculosa,* but is rather more restricted on either side.

It is extremely common in the whole Greenbrier and New River drainages. It is also found in the upper Tennessee. On the eastern side it is common in the James drainage, but has not been found in the Roanoke, and besides, it has been reported from the uppermost Shenandoah (Waynesboro, Augusta Co., Va.). Farther north, chiefly in the rest of the Potomac drainage, it is positively absent, and also on the west side it does not go into the upper Monongahela system (as *Anculosa* does).

Its presence in New River and Tennessee in forms which are specifically identical shows a closer connection of these two faunas than in any of the previous cases. We have seen that in *Cambarus bartoni,* a closely allied species, general distribution is very likely due to active or passive migration across divides. This might be true also here. But *Cambarus longulus* differs from *C. bartoni* in its ecological habits, inhabiting preferably larger mountain streams, and not the smallest headwaters or even springs, as *C. bartoni* does. For all practical purposes we may compare *C. longulus* with *Anculosa,* and whatever the means were which permitted *Anculosa* to get from the Tennessee into the New River, might have worked as well in the case of this crayfish. Having reached the New and Green-

brier, it did not go beyond this drainage on the western side and did not reach upper Tygart and Cheat as *Anculosa* did. The reasons for this as well as for the fact that it did not become specifically distinct in New River are unknown for the present, but probably they are to be found in a difference of the time of migration from that of *Anculosa*.

From New River, *C. longulus* got into James River by the same means as *Symphynota tappaniana* and *Anculosa*, *i. e.*, by stream capture. It did not get out of this drainage except at one place, in the uppermost Shenandoah. This is probably to be connected with the stream piracy committed by the Shenandoah all along its present valley (see above, p. 347). Just at Waynesboro there is a wind gap in the Blue Ridge, Rockfish Gap, which undoubtedly once served as an outlet for a tributary of the James River (Rockfish Creek or Mechum River), which was beheaded by the Shenandoah exactly as was Beaverdam Creek at Snickers Gap (Davis, 1891, p. 576).

The question remains, why *C. longulus* did not spread over the rest of the Shenandoah and Potomac drainage. This may be due to ecological causes. The species may not find farther down in the Shenandoah a congenial environment. Where I found *C. longulus* the water was always rough and full of rocks, and the lower Shenandoah, although by no means a sluggish river, has considerable quiet stretches. I also found this species generally at elevations higher than the Shenandoah in the average. This would correspond to a degree to the conditions seen in *C. bartoni*, which is also a species avoiding larger streams and quiet water.

Taking these last three cases together, *Symphynota tappaniana*, *Anculosa*, and *Cambarus longulus*, it is seen that, although they differ in particulars, they fall under one general head, and that very likely similar causes were working to effect their distribution. Disregarding *Strophitus* and *Alasmidonta*, which probably crossed the divide farther north, they are the only cases where freshwater forms seem to have crossed the Allegheny divide in its central parts, probably by the help of stream capture.

The total number of such cases is very small compared with the numerous cases which follow the general rule, that the Allegheny

Mountains have formed and are forming a sharp barrier between the western and eastern fauna. But this is exactly what was to be expected, for the distribution of freshwater animals is primarily governed by the conformation of the drainage systems and their boundaries, provided there are no exceptional means of dispersal which permit a transport or migration over land.

Special Cases.

So far we have attempted to explain those cases which submitted to a classification such as has been given above (Chapter 4, pp. 338–341). But perusing the end of Chapter 2 (pp. 324, 325), we see that not all forms have been treated and that there are among the *Najades* at least three others which show special features. These are: *Margaritana margaritifera, Eurynia constricta, Eurynia nasuta.*

We may pass over *Eurynia constricta* with a few words. This species belongs undoubtedly to the southern element in the Atlantic fauna, and has been treated with it above. The peculiarity in this case is that it has an extremely closely allied species in the headwaters of the Holston (and elsewhere in the Tennessee drainage). It might be possible that here we have evidence of a direct crossing from the Holston into the Atlantic drainage. But as far as we know, the two species do not come in close contact with each other in the region investigated, and if there is any contact it is somewhere else, probably in the southern Appalachians, and this case thus would belong to the Tennessee-Coosa problem. It should be added that probably also two crayfishes fall into the same class, *Cambarus acuminatus* and *C. spinosus.*

The other two cases must be treated separately, each forming a class by itself.

Margaritana margaritifera.

In our region this species is found exclusively in the upper Schuylkill drainage in Pennsylvania (Schuylkill Co.). This is the only locality known outside (to the south) of the terminal Moraine. Farther to the northeast, within the Glacial area, in New York and New England, and all the way to New Foundland, this species is rather abundant. In addition, it is found (in a somewhat different

form) in northwestern North America and in absolutely the same form in Iceland and parts of Europe and Asia. The distributional facts have been summarized by Walker (1910), and as to the origin of the distribution he draws the conclusion (*l. c.*, p. 139) that the presence of this species in northeastern North America is best explained by the assumption that it immigrated, probably in late Tertiary times, from Europe by a land-bridge over Iceland and Greenland.

I accept this fully. Also the idea of Walker, that the Glacial epoch restricted the range of this species, must be accepted. In fact, we are to regard the present station in Pennsylvania as *the last remnant of the Glacial refugium* of this species, just in front of the terminal Moraine. Here it survived and the present distribution is largely a Postglacial re-occupation of lost territory,[28] and in this it fully agrees with the other Atlantic forms, chiefly the northern element. It differs, however, from the latter in its ecological preferences: *Margaritana* is a form of cold water and is averse to limestone.

Thus it is evident that *Margaritana* is a stranger among the other *Najades* of the Atlantic side, in fact, it is an element of the North American fauna which stands by itself and has been subject to entirely different laws in its distribution. It is true, there is a shell in the interior basin which is allied to it, but only remotely so, belonging to another genus: *Cumberlandia monodonta* (Say). Another one is *Margaritana hembeli* (Conrad) from southern Alabama and Louisiana.[29] Both of these do not seem to have any direct genetic connection with *M. margaritifera* and are probably relics of a former more general distribution of this most primitive and archaic group of *Najades*, undoubtedly reaching back in their history far beyond the other *Najades* and far into Mesozoic times.

Eurynia nasuta.

On the Atlantic side this species is found from the Delaware

[28] It is doubtful, whether all of the present range was regained from this Pennsylvanian stock; it is quite possible, that there were other refugia, situated on the former seaward extension of the present coast. The Pennsylvanian refugium is the only one, which has been positively ascertained.

[29] The so called *Margaritana decumbens* (Lea) of Alabama is an extremely doubtful form in every respect (see Walker, *l. c.*, p. 128).

River estuary northward, and goes probably a little farther south on the Coastal Plain into Virginia. In this distribution it would agree very well with the northern stock of the Atlantic fauna. But it differs from the members belonging to this in that it has no representative species in the upper Ohio basin. However, it is found on the western side of the Alleghenies and is widely distributed in the lake drainage, chiefly in Lake Erie and the state of Michigan, and it is absolutely the same form that is found there. The fact is that these ranges are not disconnected, but appear to be rather continuous across the state of New York and the known localities follow in a general way the line of the present Erie canal from Buffalo to the Hudson River at Albany. This region lies outside the scope of the present paper, but it should be mentioned here that there are other western species of *Najades* which follow the same line of dispersal eastward from the St. Lawrence drainage to Hudson River. It is very likely that *Eurynia nasuta* belongs to this group, and it probably is the one of them which has reached in modern times the widest dispersal upon the Atlantic side. Its western origin is confirmed by the fact that the only species allied to it, *Eurynia subrostrata* (Say), is western and is found in the central and western parts of the interior basin in large, quiet rivers, ponds and lakes, avoiding rough water and strong current. For this reason, probably, it is not found in the upper Ohio drainage. This species has crossed somewhere in the region from northern Illinois to northern Ohio into the lake drainage, developed there into the species *nasuta*, which then spread eastward, following the quiet waters of the lakes and those of the canal till it reached the estuary of the Hudson. Thence it had no difficulty to spread farther over the Coastal Plain and reached across New Jersey[30] the lower Delaware, and even beyond. Also on the Atlantic side it preserves its preference for lakes, estuaries, canals, etc., that is to say, for quiet water.

We thus are to regard *Eurynia nasuta* as a quite recent immigrant in the Atlantic drainage, belonging surely to the Postglacial time, and this immigration might have been completed even by the

[30] It is present, for instance, in the Delaware-Raritan canal at Princeton, N. J.

help of the modern, artificial canals. But, of course, it is difficult to decide positively whether canals have played a necessary part in this dispersal. This question should be investigated in connection with the other western forms, which have taken the route of the Erie canal; but this is not our present object.

The above studies would be more complete if the conclusions were supported by *paleontological evidence;* if we had fossil remnants of *Najades* or other aquatic creatures which would give us an idea as to the faunas of the two watersheds in the past, chiefly during Tertiary times. It is very much to be regretted that practically nothing is known in this line.

There is indeed a famous locality, Fish House, Camden Co., New Jersey, opposite Philadelphia, which has yielded fossil *Najades,* probably belonging to the Glacial time. These shells have been described and discussed by Lea and chiefly by Whitfield (Mon. U. S. Geol. Surv., 9, 1885), and their geological age has been ascertained by Woolman (Ann. Rep. Geol. Surv. N. J. (for 1896), 1897, p. 201 ff.), Pilsbry (*Pr. Ac. Philad.,* 1896, p. 567) and Simpson (Pr. U. S. Mus., 1895, p. 338). But for the present time these fossils are absolutely useless, because western affinities have been maintained for these species, which surely do not exist. The species have been identified mainly from casts, and Lea as well as Whitfield have indicated, by the names given to them, their supposed affinities to western species. I have taken the trouble of making plaster casts of the inside of specimens of the living species with which they have been correlated, and practically in all cases it became evident at a glance that there was no similarity at all.

But this should be the subject of a special paper. It suffices here to make the statement, first, that the number of species described from this deposit (about a dozen) should be reduced to not more than three or four, and second, that there is not a single one which has distinct and unmistakable affinities to any typical western species.

SUMMARY OF CONCLUSIONS.

1. I think that the present studies have demonstrated the fundamental fact, *that certain freshwater animals are apt to furnish important evidence for past conditions of drainage by their present distribution,* while others are not. The most important of the former are the *Najades.* There are many cases (not only in our region) where indentical or closely allied species are found in different drainage systems which have at present no direct water connection. Such cases are generally restricted to *limited, well-defined regions.*

In our region we have seen that such cases exist in the mountains in the section which has the upper New River for its center; but similar instances are known in Pennsylvania, in the headwaters of the Susquehanna.

This *localisation* is the most important evidence against the assumption that passive transport over land has played a part in these cases: if this was possible at all, or if it was a factor to be considered, evidence for this should be general. But just where we might expect that transport should have worked by all means, there is no evidence whatever for it. This is most especially true in the case of the divide between the upper Tennessee drainage and that of New River. If *Najades* should be able to cross divides by being transported, it should have happened just here. Also the general condition of the eastern and western fauna, its dissimilarity, shows that *Najades* were not transported across the mountains.

Very likely the freshwater snails of the family *Pleuroceridæ* submit to the same general law as the *Najades* and are important for the study of the old drainage features. But they should be further studied, chiefly with regard to their actual distribution, their systematics and relationships. Finally, some crayfishes of the genus *Cambarus* are extremely valuable in this respect, but unfortunately their number is not great.

2. *The Allegheny system forms an old and very well-marked boundary between aquatic animals inhabiting the interior basin and the Atlantic slope.* This barrier may have been rendered insignifi-

cant at certain times in the past. But beginning with the Postcretaceous elevation of the country and the subsequent rejuvenation of all drainage systems, this barrier has been emphasized again and persists to the present time.

3. *The uniformity of the fauna of the upper Ohio basin is a character acquired in Postglacial times*, and it has been shown that not only Big Sandy River, but also Licking River, and possibly also Kentucky River, belong to the upper Ohio basin, and not to the Cumberland-Tennessee drainage. In this case *zoögeographical evidence contributes to the solution of a question which has not been fully settled by physiographical methods.*

4. *On the western side we have remnants of an older (Preglacial) faunistic differentiation.* The most important division is the Tennessee-Cumberland fauna, of which, however, only a small part has been considered in the present paper, and which deserves more detailed study. Other remnants of what might be Preglacial faunas are possibly seen in the headwaters of the Monongahela and Kanawha rivers. But in these cases the physiographical development of these parts must be studied more closely before we can arrive at a final conclusion.

5. *The Atlantic fauna is a distinct fauna and the creation of two faunal provinces, Mississippian and Atlantic* (Simpson, 1900, p. 505), *is fully justified.* Nevertheless, the Atlantic fauna is a secondary one, derived originally from that of the interior basin, and its chief character consists in the absence of a great number of types of the interior basin.

6. *Within the Atlantic fauna we have to distinguish two main elements, a northern and a southern.* The northern came from the interior basin around the northern end of the Alleghenies; the southern came around the southern end. The former belongs to the Preglacial time, but is not very old, while in the latter there are some rather ancient elements, going back possibly to the earlier Tertiary, or even beyond. The southern element probably is closely connected with the Tennessee-Coosa problem.

7. *Along the Atlantic slope we have a dispersal line directed both north and south*, which has been clearly recognized, for land-forms,

by Adams (1902 and 1905). But this route was available *also for aquatic forms of life* and lies probably mainly upon the Coastal Plain, where barriers are largely removed by base-leveling. To a smaller degree stream piracy in the uplands may have played a part in the dispersal of the Atlantic forms.

8. *In the mountains we know a few cases which indicate crossing of the divide,* but compared with the mass of the fauna, these cases are very insignificant. However, they are zoögraphically of the greatest interest in so far as *they indicate probable cases of stream capture.* In order to properly understand these cases, the physiography of the region involved should be studied more closely.

9. *In addition, we have on the Atlantic side a few cases of abnormal distribution for which special explanations have been advanced.* One of them concerns a form, *Margaritana margaritifera,* which differs in the origin of its distribution entirely from all North American *Najades,*[31] and which is a stranger in our fauna. The other case, *Eurynia nasuta,* possibly is due to Postglacial migration from the St. Lawrence basin to the Atlantic slope, and may be in part quite recent.

10. *Further investigations* should be made primarily in the region of the southern Atlantic slope and in the southern Appalachians, and should be connected with the study of the Tennessee-Coosa problem from the zoögeographical side. In this region there are extremely interesting conditions, which, however, are very unsatisfactorily known, and have led Johnson (1905) to the erroneous assumption that the evidence taken from the *Najades* is unreliable with regard to the reconstruction of the old drainage systems.

In addition, other freshwater groups should be studied. In the present paper the *Najades* have furnished the chief evidence, but it has been shown that also certain *Gastropods* and the *Crayfishes* are or might be valuable; but there are surely other groups, chiefly the Fishes.

[31] At present, only a land snail, *Helix hortensis* Muell., falls under the same head.

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Carnegie Museum,
Pittsburgh, Pa.,
April 18, 1913.

EXPLANATION OF PLATE XII.

MAP OF THE ALLEGHENY SYSTEM OF VIRGINIA, WEST VIRGINIA, MARYLAND AND PENNSYLVANIA.

The chief *Physiographical Divisions* are:

AP: Allegheny Plateau; *AM:* Allegheny Mountains; *AV:* Allegheny valley; *PP:* Piedmont Plateau; *CP:* Coastal Plain. They are marked off by heavy dotted lines. From the upper Clinch River to Covington, on Jackson River, runs another dotted line, which indicates the chief *fault* of this region, discussed in chapter 5, p. 345. The line of heavy dashes represents the *divide* between the Interior Basin drainage in the West, and that of the Atlantic Slope (including the St. Lawrence) in the East and North.

The following abbreviations for rivers and creeks have been used:

Upper Ohio and Allegheny drainage:

All = Allegheny River.
Bv = Beaver River.
Clar = Clarion River.
Con = Conemaugh River.
Cr = Crooked Creek.
Fr = French Creek.
Kis = Kiskiminetas River.
Loy = Loyalhanna River.
Mah = Mahoning Creek.
Po = Potato Creek.
Qu = Quemahoning Creek.
RB = Red Bank Creek.

Monongahela drainage:

Bl = Blackwater River.
Bu = Buckhannon River.
DF = Dry Fork.
SF = Shavers Fork.
Tyg = Tygart Valley River.
WF = West Fork River.

Tributaries of Ohio in West Virginia and Kentucky:

F = Fish Creek.
Fg = Fishing Creek.
Hg = Hughes River.
L. Fk = Levisa Fork of Big Sandy River.
L. Kan = Little Kanawha River.
M. I. = Middle Island Creek.

Delaware drainage:

Leh = Lehigh River.
Liz = Lizard Creek.
P = Princess Creek.

Susquehanna drainage:

C. C. = Cush Cushion Creek.
Ch = Chest Creek.
Cl = Clearfield Creek.
Coned = Conedoguinet Creek.
Conew = Conewago Creek.
N.B. = North Branch of Susquehanna.
Si = Sinnemahoning Creek.
Sw = Swatara Creek.
Ti = Tioga Creek.
W. B. = West Branch of Susquehanna.

Potomac drainage:

An = Antietam Creek.
Con = Conococheague Creek.
N. B. = North Branch Potomac River.
S. B. = South Branch Potomac River.
To = Tonoloway Creek.
W = Wills Creek.

James drainage:

N = North River (headwaters called: Calf Pasture River).
RF = Rockfish Creek.
Riv = Rivanna River.

Roanoke drainage:

N. F. = North Fork Roanoke River.

Holston drainage:

Holston = North Fork Holston River.
M. F. = Middle Fork Holston River.
S. F. = South Fork Holston River.

EXPLANATION OF PLATE XIII.

Profiles of Rivers.

Fig. 1. Profile up from Pittsburgh, Pa., along Allegheny River, Mahoning and Little Mahoning Creeks to Divide, and thence down along Cush Cushion Creek, West Branch Susquehanna, and Susquehanna River to Havre de Grace, Md. (sea level).

Between Curvensville and Keating the river has not been accurately surveyed.

Compiled from: U. S. Geol. Surv. Atlas Sheets, and Hoyt and Anderson, 1905, pl. 28 and 29.

Fig. 2. Profile from a little above McKeesport, Pa., up the Monongahela and its tributaries (Youghiogheny, Cheat and Shavers Fork, Tygart Valley River, West Fork River) to the Divide, and thence down the South and North Branch and the Potomac River, to Washington, D. C.

The sources of Shavers Fork and South Branch Potomac are about twenty miles apart. On account of the exaggerated vertical scale, the headwaters of all rivers appear much longer than they actually are.

Compiled from: U. S. Geol. Surv. Atlas Sheets, and Bolster, 1907, pl. 5 and 6.

EXPLANATION OF PLATE XIV.

Profiles of Rivers and Mountains.

Fig. 1. Profile from Charleston, W. Va., up the Kanawha, New and Greenbrier Rivers, to the Divide, and thence down the Jackson and North Rivers to Lynchburg, Va., on James River. Also the profile of the upper Roanoke is given and its location with reference to New River, and the old abandoned valley connecting the two. The upper parts of New River are only roughly sketched.

The sources of Greenbrier and Jackson Rivers are about fifteen miles apart.

Compiled from U. S. Geol. Surv. Atlas Sheets.

Fig. 2. Profile along the crest of the Allegheny Front, and the ranges farther south (Peters and East River Mountains), which form its continuation. The rivers and creeks at the eastern foot of the mountains are indicated by dotted lines. In the region of the B. & O. Tunnel exact data are missing. The two sections of the profile are connected at $x-y$. The range behind Dans Mountain is Savage and Backbone Mountain.

Compiled from U. S. Geol. Surv. Atlas Sheets.

Explanation of abbreviations:

Streams:

Cl = South Fork Clinch River.
St = Stony Creek.
Du = Dunlap Creek.
N. Fk. S. Br. Pot. = North Fork of South Branch Potomac.
N. Br. = North Branch Potomac.
Ray = Raystown Branch Juniata Riv.
Dun = Dunning Creek.
Fra. Jun. = Frankstown Branch Juniata River.
W. G. = Water Gaps (of New River, flowing West, and of Potomac, flowing East).

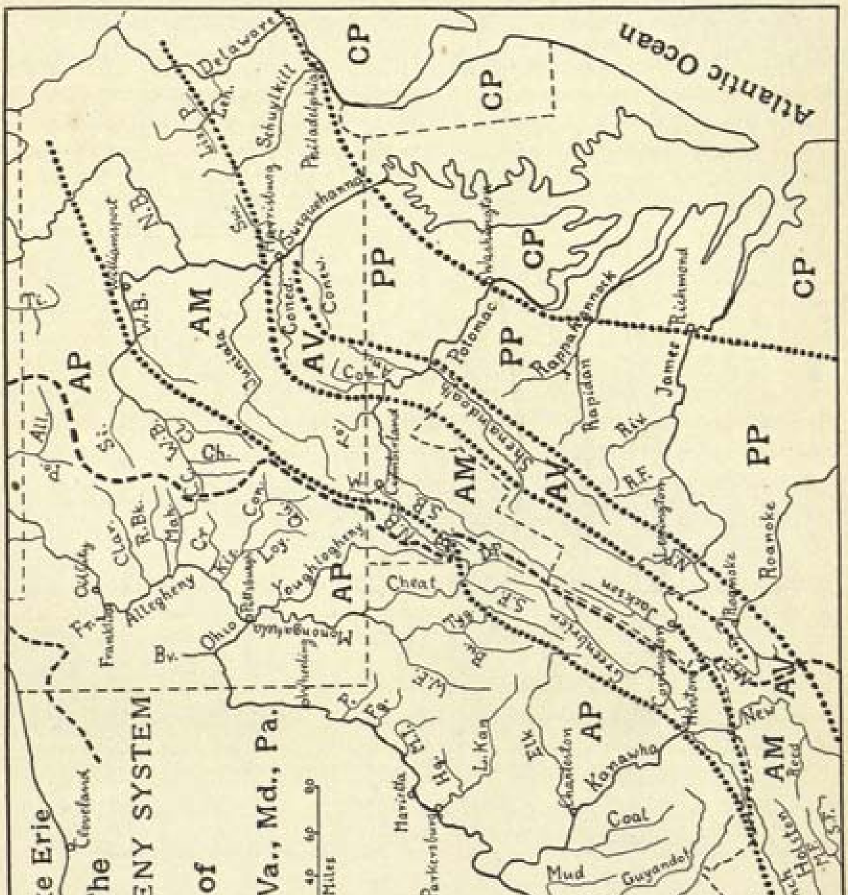
Towns:

Cov = Covington, Va.
Pet = Petersburg, W. Va.
Cumb = Cumberland, Md.
Holl = Hollidaysburg, Pa.

Tunnels:

C. & O. = Chesapeake and Ohio R. R.
B. & O. = Baltimore and Ohio R. R.
P. R. R. = Pennsylvania R. R.

It is believed that the depression in the region of the C. & O. Tunnel is a remnant of the Cretaceous Peneplain.


The
ALLEGHENY SYSTEM
of
Va., W. Va., Md., Pa.
Miles
Lake Erie
Atlantic Ocean
AP
AM
AV
PP
CP
Delaware
Schuylkill
Philadelphia
Susquehanna
Harrisburg
Potomac
Washington
Rappahannock
Rapidan
Richmond
James
Shenandoah
Roanoke
Cheat
Youghiogheny
Allegheny
Ohio
Monongahela
Kanawha
Charleston
Coal
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Big Sandy
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Clinch
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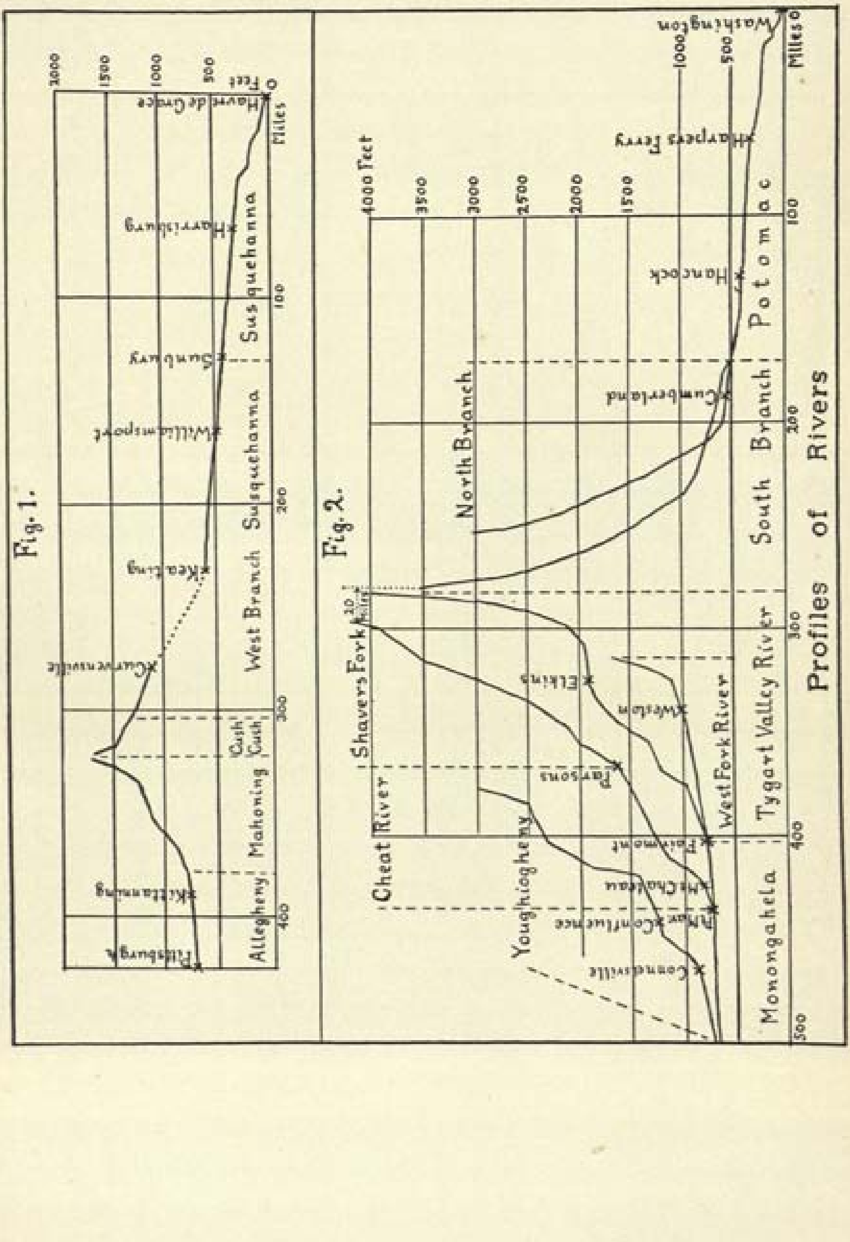
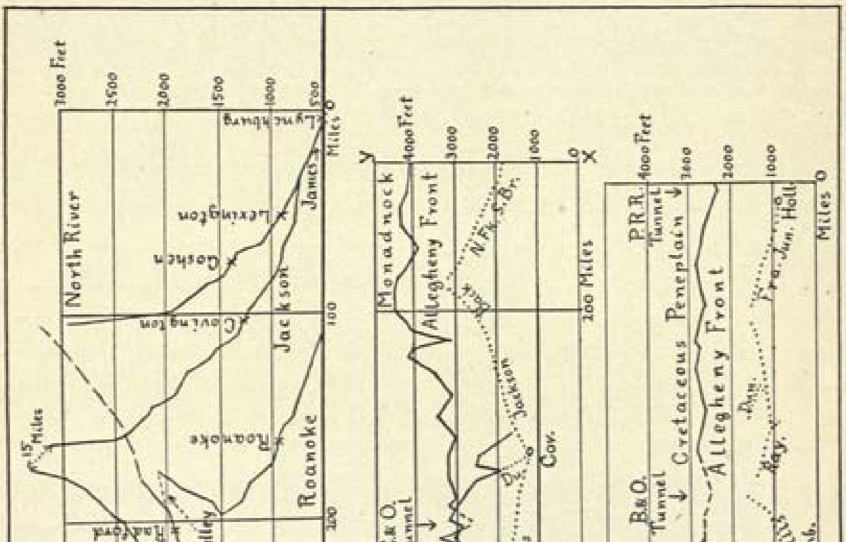
Greenbrier
Lexington
Parkersburg
Marietta



Profiles of Rivers


Profiles
of
Rivers & Mountains
Fig. 1.
Greenbrier
North River
Kanawha
New River
Roanoke
Jackson
James
Old Valley
Charleston
Kanawha Falls
Hinton
Ronceverte
Radford
Covington
Goshen
Lexington
Lynchburg
Fig. 2.
Monadnock
Allegheny Front
C. & O. Tunnel
W.G.
East River Mtn.
Peters Mtn.
B. & O. Tunnel
P.R.R. Tunnel
Cretaceous Peneplain
Dans Mtn.
Miles

THE RELATION BETWEEN THE PHYSICAL STATE OF BRAIN CELLS AND BRAIN FUNCTIONS,—EXPERIMENTAL AND CLINICAL.

By GEO. W. CRILE, M.D.

(*Read April 18, 1913.*)

The brain in all animals (including man) is but the clearing-house for reactions to environment,—for animals are essentially motor or neuro-motor mechanisms, composed of many parts, it is true, but integrated by the nervous system. Throughout the phylogenetic history of the race the stimuli of environment have driven this mechanism, whose seat of power—the battery—is the brain.

Since all normal life depends upon the response of the brain to the daily stimuli, we should expect in health as well as in disease to find modifications of the functions and the physical state of the component parts of this central battery—the brain cells. Although we must believe, then, that every reaction to stimuli, however slight, produces a corresponding change in the brain cells, yet there are certain normal, that is, non-diseased conditions which produce especially striking changes. The cell changes due to the emotions, for example, are so similar, and in extreme conditions approach so closely to the changes produced by disease, that it is impossible to say where the normal ceases and the abnormal begins.

In view of the similarity of brain cell changes, it is not strange that in the clinic as well as in daily life, we are confronted constantly by outward manifestations so nearly identical that the true underlying cause of the condition is too often overlooked or misunderstood. In our laboratory experiments and our clinical observations we have found that exhaustion from intense emotion, from prolonged physical exertion, from insomnia, from intense fear, certain toxemias, hemorrhage, and the conditions commonly denominated sur-

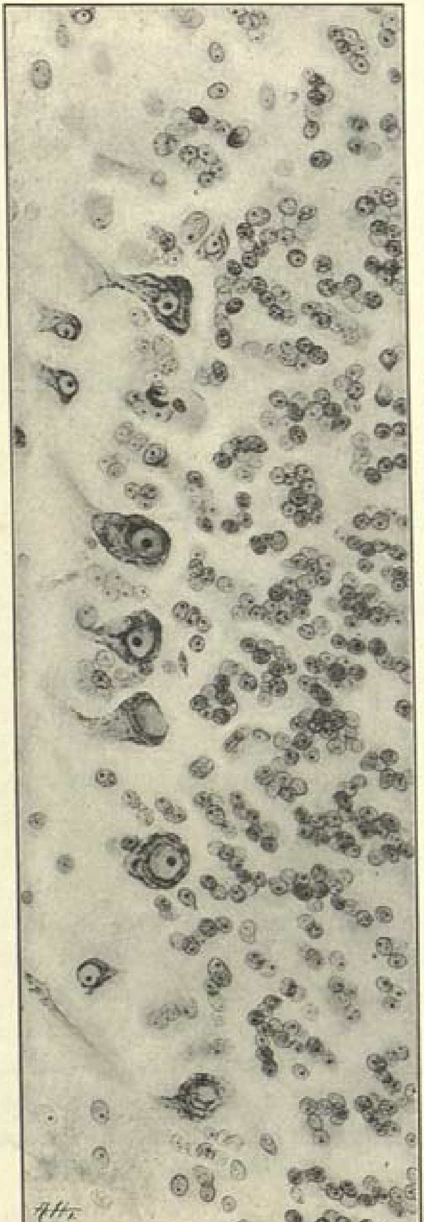


FIG. 1. Area from cerebellum, rabbit, normal.

gical shock, produce similar outward manifestations and identical brain cell changes.

It is, therefore, the purpose of this paper to present the definite results of certain laboratory researches which show certain relations between the alteration in brain functions and alterations in the brain cells.

FEAR.—Our experiments showed that the brain cell changes due to fear may be divided into two stages: First, that of hyperchromatism—stimulation; second, that of hypochromatism—exhaustion. Hyperchromatism was shown only in the presence of the activating stimuli or within a very short time after they had been received. This state gradually changed until the period of maximum exhaustion was reached, about six hours later. Then a process of reconstruction began and continued until the normal state was again reached.

FATIGUE.—Fatigue from overexertion produced in the brain cells like changes to those produced by fear, these changes being proportional to the amount of exertion. In the extreme stage of exhaustion from this cause we found that the total quantity of Nissl substance was enormously reduced. If the exertion is too greatly prolonged, it may take weeks or months for the cells to be restored to their normal condition. In fact, in exhaustion from the emotions or from physical work a certain number of brain cells are permanently lost. This probably explains the fact that an athlete or a race horse trained to the point of highest efficiency can but once in his life reach his maximum record. Under certain conditions, however, it may be possible that though some chromatin is forever lost, the remainder may be so remarkably developed that for a time at least it will compensate for that which is gone.

HEMORRHAGE.—The loss of blood from any cause, if sufficient to reduce the blood pressure, will occasion a change in the brain cells, provided the period of hypotension lasts more than five minutes. This time limit is a safeguard against permanent injury from the temporary hypotension which causes one to faint. If the hemorrhage is long continued and the blood pressure is low, there will be a permanent loss of some of the brain cells. This is why an indi-

vidual will never again be restored to his original powers after suffering from a prolonged hemorrhage.

Drugs.—According to their effect upon the brain cells, drugs may be divided into three classes: First, those that stimulate brain cells to increased activity,—as strychnine; second, those that chemically

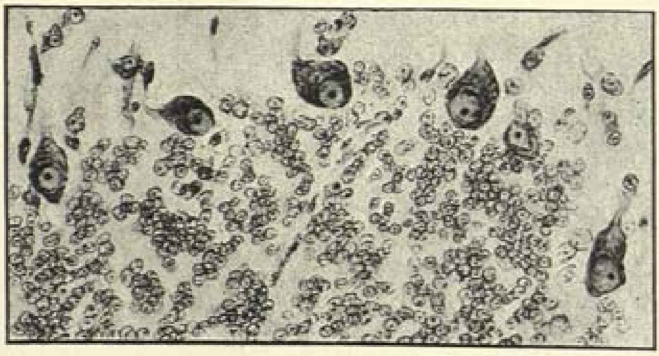


Fig. 2. Area from cerebellum, rabbit, during fright.

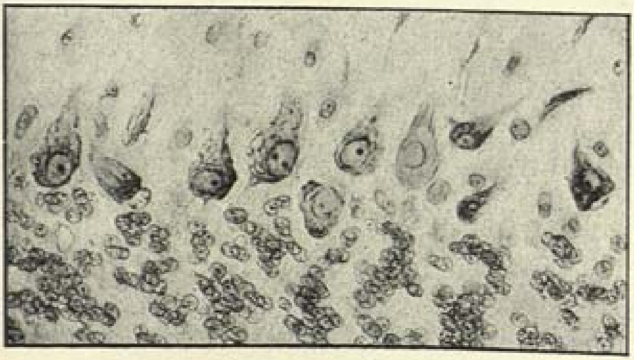


Fig. 3. Area from cerebellum, rabbit, 6 hours after fright.

destroy the brain cells,—as alcohol and iodoform; third, those that suspend the functions of the cells without damaging them,—as nitrous oxide, ether, morphia. Our experiments showed that brain cell changes induced by drugs of the first class are precisely the same as the cycle of changes produced by the emotions and physical

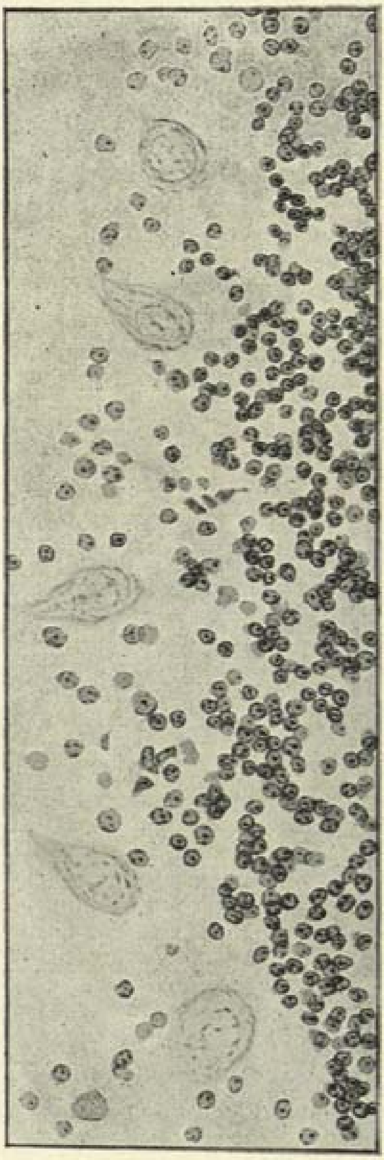


Fig. 4. Area from cerebellum, delirium tremens.

activity. We found that strychnia, according to the dosage, caused convulsions ending in exhaustion and death; excitation followed by lassitude; stimulation without notable after results; or increased mental *tone*. The brain cells accurately displayed these physiologic alterations in proportional hyperchromatism in the active stages, and proportional chromatolysis in the stages of reaction. The biologic and therapeutic application of this proof is as obvious as it is important.

Alcohol in large and repeated dosage caused marked morphologic changes in the brain cells which went as far even as destruction of the cells. Ether, on the other hand, even after five hours of administration, produced no observable destructive changes in the cells.

The effect of iodoform was peculiarly interesting, as it was the only drug that produced fever. Its observed effect upon the brain cells was that of widespread destruction.

INFECTIONS.—In every observation on dogs and on man pyogenic infections caused definite and demonstrable lesions in certain cells of the nervous system, the changes in the cortex and the cerebellum being most marked. For example, in infections the result of bowel obstruction, in peritonitis, and in osteomyelitis causing death, the real lesion is in the brain cells. The lassitude, diminished mental power, excitability, irritability, restlessness, delirium and unconsciousness that may be associated with acute infections, we may reasonably conclude are due to physical changes in the brain cells.

GRAVES' DISEASE.—In Graves' disease the brain cells showed marked changes which were apparently the same as those produced by overwork, by the emotions, and by strychnine. In one advanced case it was found that the brain had lost permanently a large number of cells. This is the reason undoubtedly why a severe case of exophthalmic goitre sustains such a permanent loss of brain power.

INSOMNIA.—The brains of rabbits which had been kept awake for 100 hours showed precisely the same changes as those shown in physical fatigue, strychnine poisoning and exhaustion from emotional stimulation. Eight hours of continuous sleep restored all the cells except those that had been completely exhausted. This will explain the permanent effect of long-continued insomnia;—that is,

Fig. 5. Area from cerebellum, iodoform poisoning.

long-continued insomnia permanently destroys a part of the brain cells just as do too great physical exertion, certain drugs, emotional strain, exophthalmic goitre or hemorrhage. We found, however, that if instead of natural sleep the rabbits were placed for the same number of hours under nitrous oxide anesthesia, not only were the brain cells prevented from physical deterioration, but that 90 per cent. of them became hyperchromatic. This gives us a possible clue to the actual chemical effect of sleep. For since nitrous oxide owes its anesthetic effect to its influence upon oxidation, we may

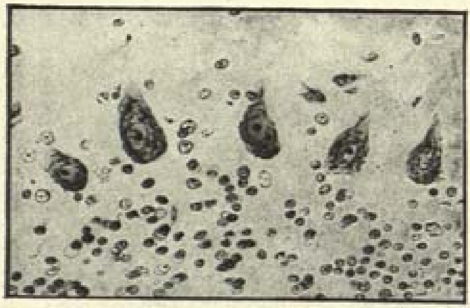


FIG. 6. Area from cerebellum, woodchuck, hibernating.

infer that sleep also is a question of oxidation of the cell content. If this is true, then it is probable that inhalation anesthetics exert their peculiar influence upon that portion of the brain through which sleep itself is produced. If nitrous oxide anesthesia and sleep are chemically identical, then we have a further clue to one of the primary mechanisms of life itself; and as a practical corollary one might be able to produce artificial sleep very closely resembling normal sleep, and with this advantage,—that by using an anesthetic interfering with oxidation the brain cells might be reconstructed after physical fatigue, after emotional strain, or after the depression of disease.

In the case of the rabbit in which nitrous oxide was substituted for sleep the appearance of the brain cells resembled those in but one other group experimentally examined,—the hibernating woodchucks.

INSANITY.—Our researches have shown that in the course of a fatal disease and in fatal exhaustion, however produced, death does not ensue until there is marked disorganization of the brain tissue. In the progress of disease or exhaustion one may see in different patients every outward manifestation of mental deterioration —manifestations which, in a person who does not show any other sign of physical disease, mark him as insane. Take, for example, the progressive mental state of a brilliant scholar suffering from typhoid fever. On the first day of the gradual onset of the disease he would notice that his mental power was below its maxi-

FIG. 7. Area from cerebellum, woodchuck, after fright.

mum efficiency; on the second he would notice a further deterioration, and so the mental effect of his disease would progress until he would find it impossible to express a thought or to make a deduction. No one can be philanthropic with jaundice; no one suffering from Graves' disease can be generous; no mental process is possible in the course of the acute infectious diseases. Just prior to death from any cause everyone is in a mental state which if it could be continued would cause that individual to be judged insane. If the delirium that occurs in the course of certain diseases could be continued the patient would be judged insane. In severe cases of Graves' disease the patient is insane. Individuals may be temporarily insane under overwhelming emotion. Every clinician has seen great numbers of

cases of insanity as phases of a disease, of an injury, or of an emotion. The stage of excitation in anesthesia is insanity. The only difference between what is conventionally called insanity and the fleeting insanity of the sick and the injured is that of time. We may conclude, therefore, what must be the brain picture of the person who is permanently insane. This *a priori* reasoning is all that is possible, since the study of the brain in the insane has thus far been wholly on the brains of those who have died of some disease. And it is impossible to say which changes have been produced by the fatal disease, and which by the condition producing insanity. The only logical way of investigating the physical basis of insanity would be to make use of the very rare opportunity of studying accidental death in the insane.

Our experiments have proved conclusively that whether we call a person fatigued or diseased, the brain cells undergo physical deterioration, accompanied by loss of mental power. Even to the minutest detail we can show a direct relationship between the physical state of the brain cells and the mental power of the individual,—that is, the physical power of a person goes *pari passu* with his mental power. Indeed, it is impossible to conceive how any mental action, however subtle, can occur without a corresponding change in the nerve cells. It is possible now to measure only the evidences of gross and violent mental activity on the brain cells. At some future time it will doubtless be possible to so refine the technique that more subtle changes may similarly be measured. Nevertheless, with the means at our disposal we have shown already that in all these conditions the cells of the cortex showed the greatest changes; and that loss of the higher mental functions accompanied the cell deterioration.

Cleveland, Ohio,
April, 1913.

RADIATED AND RECEIVED ENERGY IN RADIO-TELEGRAPHY.

By L. W. AUSTIN.

(*Read April 19, 1913.*)

Duddell and Taylor[1] were the first experimenters to attempt to determine the laws relating currents in the sending and receiving antennas used in radiotelegraphy. Their first experiments were carried on near London with distances of only a few hundred yards between the antennas. A little later these experiments were repeated on a larger scale on the Irish Sea between a land station and the steamer *Monarch*, the experiments in this case being extended up to about sixty miles. Their work served to show that up to the distances mentioned the received current fell off directly in proportion to the distance in accordance with the Hertzian equation for the electric force in the equatorial plane of an oscillator.

The determination of this law at once aroused great hopes in the minds of all workers in radiotelegraphy for the establishment of long distance communication. It was well known that with 2 K.W. and with moderate sized antennas it was quite possible to send messages over distances of three hundred miles in the daytime. From this it was easily calculated in accordance with the Duddell and Taylor law, that it would be necessary to use only 10 K.W. with antennas 400 feet high to carry on communication up to 3,000 miles. When the attempt was made, however, it was found that only on exceptionally favorable nights was any communication at all possible, even with two or three times the calculated power, and of course none at all in the daytime. This showed at once that the Duddell and Taylor law was not applicable at great distances, and it began to be assumed that for communication over water an absorption

[1] Duddell and Taylor, *Electrician*, 55, p. 260, 1905.

existed similar to that which had long been recognized in overland communication.

In 1909/10 the United States Navy carried on experiments between the high power Fessenden station at Brant Rock and the scout cruisers *Birmingham* and *Salem*.[2] In these experiments regular day communication[3] was obtained up to 800 miles between the ships, and about 1,200 miles between the high power station and the ships. Quantitative experiments on the effect of the height of sending and receiving antennas were also carried on at this time, which verified the results of Marconi, Duddell and Taylor, and Pierce. The results of all this work were finally summarized in the formula

$$I_R = 4.25 \frac{h_1 h_2}{\lambda d} I_S \epsilon^{-\frac{\alpha d}{\sqrt{\lambda}}}, \tag{1}$$

where I_R is the receiving antenna current, I_S the sending antenna current, h_1 and h_2 the heights to the centers of capacity of the two antennas, λ the wave-length, and d the distance; the currents being measured in amperes and the lengths in kilometers. In this formula the resistance of the receiving antenna was arbitrarily taken as 25 ohms, that being the resistance of the Brant Rock station under the conditions of experiment. That the resistance was the same at both wave-lengths used (1,000 meters and 3,750 meters) was due to the fact that a series condenser was used in the Brant Rock antenna at the shorter wave-length. On the ships, however, there was undoubtedly a very considerable difference in resistance at the different wave-lengths. As a matter of fact, we have never had an opportunity to measure accurately the antenna resistance on these ships. From measurements on other ships, however, it is estimated that the antenna resistance at 1,000 meters would be from 15 to 18 ohms, while at 3,750 meters it would probably be about 35 ohms. No more quantitative work at long distances was carried on by the Navy Department until the autumn of 1912, although in the meantime a number of observations were made at moderate distances which all

[2] Bulletin Bureau of Standards, 7, p. 315, 1911.

[3] Night signals, while generally stronger than those in the day time, are freakish and irregular and unfitted for quantitative comparisons.

tended to verify the general accuracy of our formula. The new series of experiments has been made in connection with the high power naval station at Arlington, Va. This station was equipped by the National Electric Signaling Co. with a 100-K.W. rotary gap sending set, and was intended for communication with the Canal Zone and with the fleet in the North Atlantic Ocean. The original plan for the antenna as submitted by the National Electric Signaling Co. showed an umbrella supported by a single tower 600 ft. high. The experiments at Brant Rock, however, showed the experts of the Navy Department that an umbrella antenna gave a center of capacity too low for the most effective working. In fact, comparative results indicated that the effective height was but little if any higher than the bottom of the umbrella, about 150 ft. in the case of the Brant Rock tower, although the total height was 420. For this reason the Arlington station has been supplied with a platform antenna supported by three towers about 400 ft. between centers, one being 600 ft. high and the other two 450 ft. The antenna has been put up in sections and consists of two flat top antennas 350 ft. long, and one 315 ft. long. These are 88 ft. wide with 23 wires each. The triangular space between the flat tops is filled in with a triangular fan of 25 wires supported independently of the flat top sections. The vertical portion of the antenna consists of a fan of 23 wires, 88 ft. wide at the top, narrowing to 10 ft. at 75 ft. above the earth, from which point the wires are brought down in a cage of the Fessenden type. The capacity of this antenna is 0.01 m.f., its natural period approximately 2,100 meters and its height to the center of capacity 400 ft. The ground system consists of a radiating network of wires covering the space between the triangle of towers and extending to some distance outside. The towers were built so that they were insulated from the earth with switches by which they could be connected with the ground net system. With the towers insulated, the antenna resistance exclusive of the inductance at a wave-length of 4,000 meters is approximately 8 ohms. Grounding the towers reduces the resistance to 1.8 ohms, and curiously enough, no perceptible difference in capacity is observed, nor is the natural period changed by more than a few meters. Theo-

retically it is difficult to understand how this great difference in antenna resistance can be produced without changing the field distribution so as to vary the capacity and wave-length, but what is still more remarkable, is that it is found that the ratio between the current in a receiving antenna a few miles distant and the sending current at Arlington remains absolutely unchanged whether the towers are grounded or insulated. But since the sending current with the towers grounded is approximately 50 per cent. larger than when the towers are insulated, they are always kept grounded. For receiving at Arlington there is practically no difference.

Referring again to the formula for the received current

$$I_R = 4.25 \frac{h_1 h_2}{\lambda d} I_S \epsilon^{-\frac{\alpha d}{\sqrt{\lambda}}},$$

it will be noticed that, if we disregard the absorption term, it bears a striking resemblance to the Hertzian equation for the amplitude of the electric force in the equatorial plane of an oscillator.[4] This equation in the form given by Zenneck is[5]

$$(2) \qquad E_0 = 2\pi \frac{lI_0}{\lambda d} 3 \cdot 10^{10} \text{ C.G.S.}$$

where E_0 is the electric amplitude at the distance d, l the length of the oscillator, and I_0 the current amplitude in the oscillator, and was derived for continuous oscillations and for an oscillator consisting of two large spheres connected by thin wires with a spark gap in the middle; an arrangement which produces a uniform current distribution throughout the wires. If we substitute the effective values of the electric field E and current I in the antennas, in place of the amplitudes, the equation will, of course, remain true. Therefore, if we are able to determine the length of the Hertzian oscillator which will be equivalent to a wireless antenna, we have at once a very convenient means of calculating the electric field at any distance not great enough to have the absorption come into play. Theoretical

[4] This applies strictly only to values of d amounting to a large number of wave-lengths.

[5] J. Zenneck, "Lehrbuch der drahtlosen Telegraphie," p. 45.

formulæ for this purpose have been given by Rudenberg,[6] and attempts have been made to apply them to the case of the scout cruisers *Birmingham* and *Salem* by H. Barckhausen[7] and myself.[8]

The formulæ are based on the assumption that if an antenna be erected on a conducting surface, its field will be the same as that of an antenna in space of twice the height, the lower portion being exactly like the real antenna but inverted beneath it; that is, the

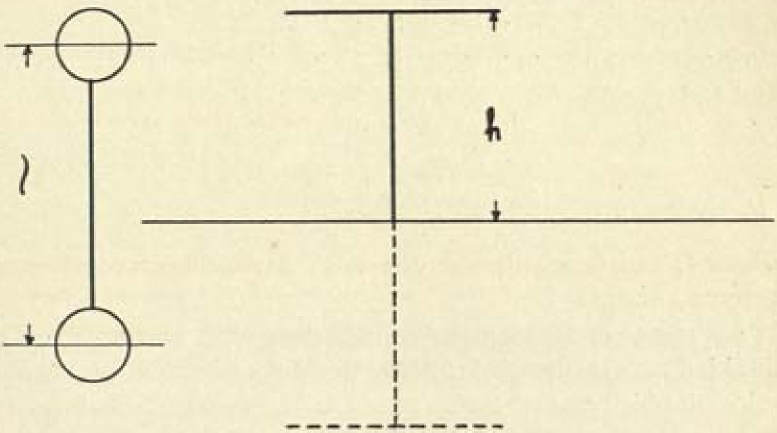


Fig. 1.

length of the equivalent Hertzian oscillator will be twice the height from the earth to the center of capacity of the antenna. As Rudenberg observes, however, the imaginary portion does not contribute to the energy radiated by the antenna. Then since the energy is proportional to l, the length of the oscillator, squared

$$l^2 = \frac{(2h)^2}{2}, \quad \text{or} \quad l = h\sqrt{2}.$$

Hence to get the length of the equivalent Hertzian oscillator we must multiply the height h to the center of capacity of the antenna by $\sqrt{2}$. In order to determine the theoretical value of the received current we must determine the electromotive force on the receiving antenna

[6] R. Rudenberg, *Ann. d. Phys.*, 25, p. 446, 1908.
[7] H. Barckhausen, *Jahrb. d. drahtlosen Telegraphie*, V., p. 261, 1912.
[8] *Journ. Wash. Acad.*, 1, p. 275, 1911.

by multiplying the effective value of the field E by the height to the center of capacity of the receiving antenna. If we are dealing with continuous oscillations, the received current will then be given by

$$I_R = \frac{Eh_2}{R} \qquad \text{(undamped oscillations)} \tag{2}$$

where R is the high frequency resistance of the receiving system.

In the case of damped oscillations, however, on account of the form of the wave train of oncoming oscillations and that of the resulting current train in the antenna, the value of the received current I_R is equal to

$$I_R = \frac{Eh_2}{R\sqrt{1 + \frac{\delta_1}{\delta_2}}}, \qquad \text{(damped oscillations)}$$

where δ_1 and δ_2 are the decrements of the sending and receiving antenna systems.

By means of thermoelements in the antennas, measurements of this kind have been made in several receiving stations in Washington using the high power station at Arlington and the station at the Washington Navy Yard for sending.[9]

The results of the calculated and observed values are given in Table I. It is seen that the observed values vary between 40 per

TABLE I.

Sending Station.	Receiving Station.	Distance.	Received Obs.	Current Cal.	Obs./Cal.
		Km.	Amp.	Amp.	%
Arlington (λ = 3900 m.)	Bureau of Standards	7.8	$5.8 \cdot 10^{-3}$	$15 \cdot 10^{-3}$	39
"	Capitol	6.4	12.0	27.5	45
"	Navy Yard	7.2	10.3	17.2	60
Navy Yard (λ = 1000 m.)	Bureau of Standards	10.0	4.1	7.6	54
"	Capitol	1.9	8.5	15.0	57

[9] In these experiments the distances between the sending and receiving stations lay between 1.5 and 10 wave-lengths. The greatest possible error due to the inapplicability of the inverse distance law to these short distances would be about 10 per cent. No evidence of ground absorption at these distances has been observed.

cent. and 60 per cent. of the calculated values; that is, the effective length of the equivalent Hertzian oscillator is apparently too great. This may be due either to the shape of the antennas or to the fact that the earth beneath them is not properly conducting as is assumed in the derivation of the formula. If the last supposition is true, a better agreement between the theoretical and observed values ought to be obtained in the case of ships' antennas where the ground consists of sea water. Unfortunately, however, in the case of warships at least, the problem is complicated by the steel masts and rigging which it is generally supposed tend to absorb a portion of the radiated energy. It is to be hoped that some time in the near future experiments may be carried out on ships free from these disturbing influences. It seems very possible that the shape of the antenna and not the conductivity of the ground is the real cause of the divergence from the theoretical values. In the case of a flat top or umbrella antenna we have nearly the condition of two plates of a condenser in which the distance between the plates is not large compared with the plate dimensions. Under these circumstances it is certain that the electric field distribution will not be the same as that due to one of the spheres of a Hertzian oscillator placed at the center of capacity of the antenna system. However this may be, the experiments show that the length of the oscillator equivalent to the antenna of a land station is somewhat less instead of greater than the height to the center of capacity.

Observations at Greater Distances.

In the Brant Rock experiments already mentioned it was found that for distances of more than 100 miles over sea water a measurable absorption of the radiated energy took place, so that to represent the received current the full form of equation (1) including the absorption factor must be used. In the experiments mentioned, observations were made on the scout cruisers up to about 1,200 miles. The figure (Fig. 2) shows that at a distance of 1,000 miles, at a wave-length of 1,000 meters, the received current was only one seventeenth of what would have been received if there had been no absorption, and since the strength of signal in the telephone is pro-

portional to the square of the received current, the signal was reduced to approximately one three-hundredth.

During the months of February and March of this year, the cruiser Salem was sent on a voyage to Gibraltar for the purpose of

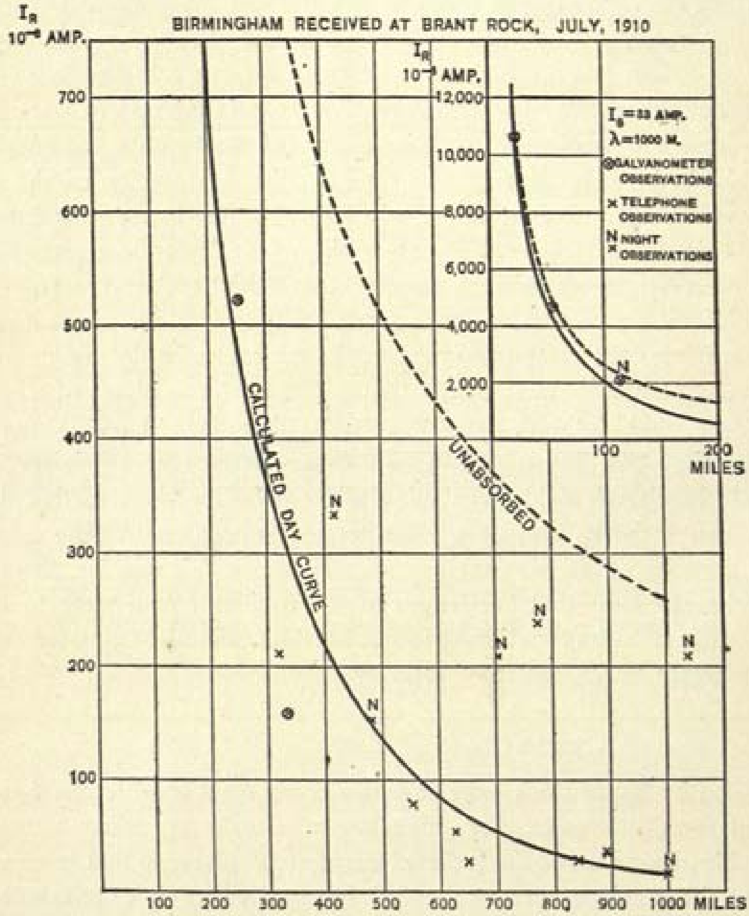


FIG. 2.

carrying out tests with the Arlington station. Successful observations with the electrolytic detector were made in the daytime up to 1,920 nautical miles, while by other detecting devices not sufficiently quantitative for measurement purposes, messages were read up to

about 2,100 nautical miles. The results of the measurements are shown in Fig. 3. The wave-length used by Arlington was 3,900 meters, and the average sending current was 110 amperes. The effective height of the Arlington antenna was 400 ft., while that of the Salem was taken as 130 ft., this being the value which was used in the calculation of the formula of the Brant Rock test. This is probably somewhat too high but is retained in the present calculation

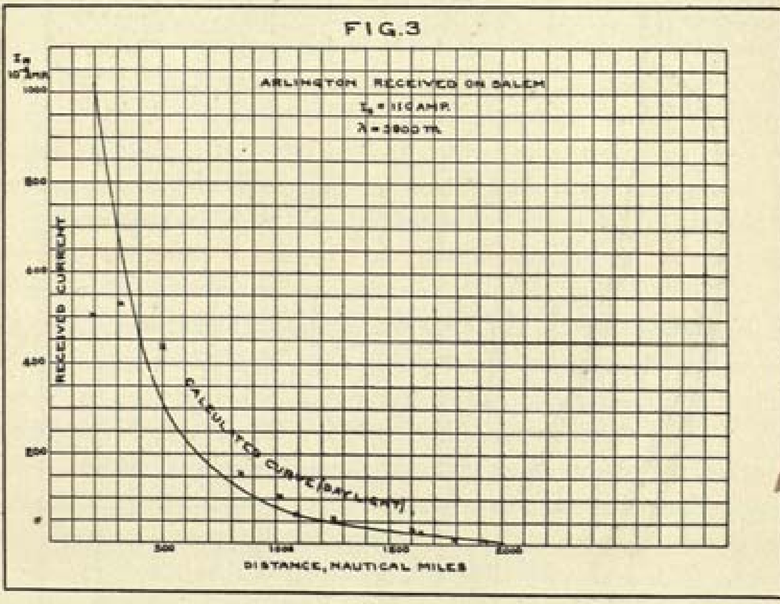


FIG. 3.

for purposes of comparison. The curve of the figure is calculated from Tables XVI. and XVIa. of the article already cited.[10] The observed values of the received currents, as indicated by the crosses in the figure, were calculated from the audibility measurements made by the shunted telephone method on the electrolytic detector in exactly the same way as in the Brant Rock experiments, except that on account of the increased efficiency of the receiving set, the least audible antenna current was taken as seven microamperes instead of ten. The observer was Mr. Lee, who also took the most impor-

[10] Bulletin Bureau of Standards, 7, p. 315, 1911.

tant observations during the Brant Rock test. Considering the difficulties of taking these measurements, the agreement with the theoretical curve is all that could be desired. It is especially to be noted that the signals became inaudible at almost the exact distance indicated by the formula.

Other Observations.

Previous to the cruise of the *Salem,* a number of observations on signals from Arlington were made in the daytime at various naval wireless stations in the United States. The results of these are shown in Fig. 4, the curve being as before the calculated value of received current over sea water, and the crosses the observed values at the various points. It will be noticed that while the observed values uniformly lie below the calculated values, the differences are not as great as would perhaps naturally be expected in transmission overland. In fact, they are in most cases not much greater than would be accounted for by the circumstances of observation. The St. Augustine observations are the only ones which were made by the calibrated detector and galvanometer method, while those at Newport, Boston, Guantanamo, Charleston and Key West were taken on uncalibrated crystal detectors by the shunted telephone method. The results show that for a wave-length of approximately 4,000 meters the ground absorption is small, at least for distances less than 1,000 miles. This is a very different result from that obtained with a 1,000 meter wave-length between New York and Washington, where the received current in the summer time is reduced to 10 per cent. of the value which it would have over salt water.[11] Of course, it must be considered, in the Arlington experiments just mentioned, that most of the stations lie on the sea coast so that the waves either pass during a portion of their course over water or might be conceived to follow along the shore rather than to pass in direct line. New Orleans is the only station in which the propagation could be considered to be entirely unaffected by the sea, and in this case the

[11] For great distances over sea, and distances of more than 100 miles over land, long waves should be used on account of their decreased absorption; while for short distances shorter waves are better on account of their more vigorous radiation.

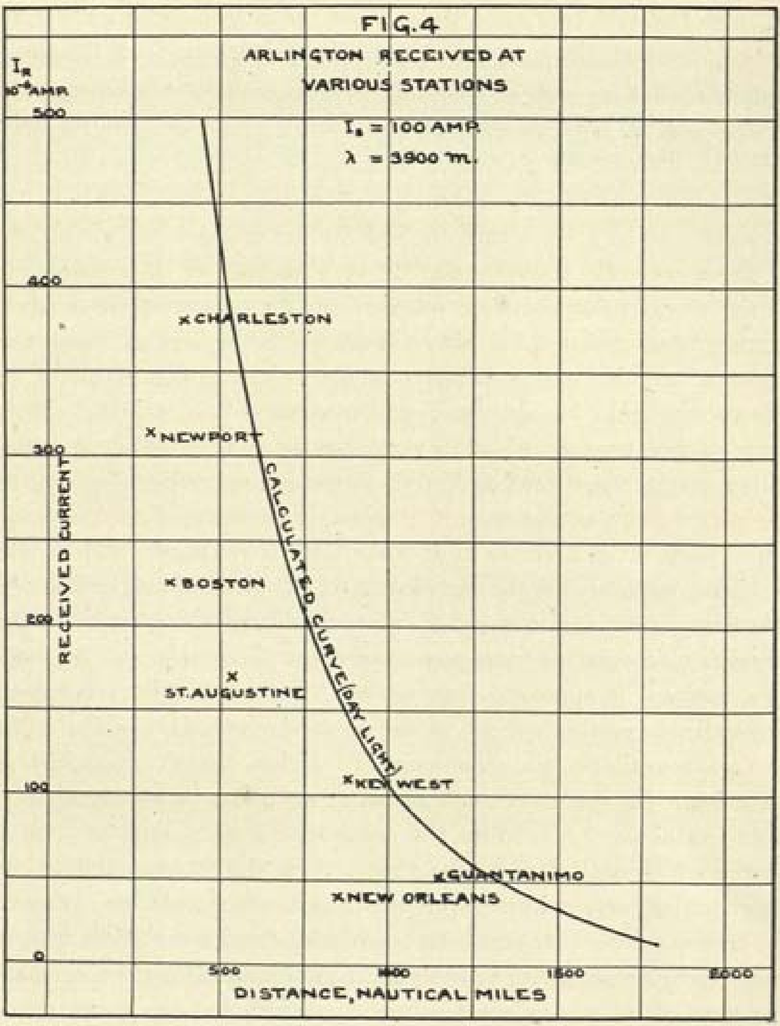


FIG. 4.

received currents lie relatively lower than for most of the other stations.

Comparison of Arc and Spark Apparatus.

It has long been claimed by advocates of the use of continuous oscillations in radiotelegraphy that these waves travel over the sur-

face of the earth with a smaller degree of absorption than the discontinuous wave trains produced by spark apparatus. In order to test this point, as well as some others connected with arc transmission, a 30-K.W. arc operated with 500-volt d.c. current was obtained. At a wave-length of 4,100 meters this arc produced from 48 to 53 amperes in the Arlington antenna. Comparisons were made of the received currents from this arc and from the spark set giving 100 to 120 amperes in the antenna. A very careful set of observations on the two types of radiation was made at St. Augustine, the received current being measured by the calibrated detector and galvanometer method. At this distance, 530 nautical miles, no difference in the absorption could be observed, the received currents being simply proportional to the radiation currents in the Arlington antenna. These results were verified by the shunted telephone method, using the slipping contact detector,[12] at New Orleans and Key West, the latter place being approximately 900 miles from Washington. The receiving apparatus was then placed on the U. S. S. *Arkansas* and taken to Colon, 1,800 nautical miles from Washington. On the voyage, although the conditions were not favorable for accurate observations, it appeared that during the daytime the arc signals gradually approached those of the spark in intensity. During the two days available for observation at Colon, the arc signals only were heard in the daytime. These observations indicated that at distances above 1,000 miles the continuous waves show a smaller degree of absorption than the waves from the spark. It was not possible, however, to draw this conclusion with certainty, since at the season of the year in which the observations were taken, exceptional days occur which might very conceivably affect the continuous oscillations in a different manner from those of the spark.[13]

Further observations were made during the recent voyage of the Salem already mentioned. Here it was found, in verification of our former conclusions, that for distances over 1,400 miles the arc as received in the day time on a special receiver was equal to or

[12] *Journ. Wash. Acad.*, I, p. 5, 1911.

[13] It is frequently observed that at night one type of wave is strengthened more than the other.

somewhat better than the spark, notwithstanding the fact that the spark radiation current at Arlington was considerably more than twice as great as the corresponding arc current. This normally, if the absorption had been equal for the two types of radiation, would have made the spark signals more than four times stronger than the arc, the amplitude of signal being proportional to the square of the high frequency current. Regular communication with both arc and spark was continued up to 2,100 miles in the day time. Several times day signals were heard at greater distances, and in these cases the arc was uniformly louder. The night signals were heard all the way to Gibraltar.

U. S. Naval Radiotelegraphic Laboratory,
April, 1913.

ELIMINATION AND NEUTRALIZATION OF TOXIC SOIL SUBSTANCES.

By OSWALD SCHREINER, Ph.D.,

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(*Read April 18, 1913.*)

The fact that certain soils are naturally infertile, or if once fertile are showing a decrease in their productive power, is a subject that has engaged the attention of many able philosophers and scientists during the centuries. Some of these have explained the infertility as being caused by the absence or diminishing quantity of the store of certain mineral soil components, others have contended that the plant in its growth excreted waste substances, much as animals do, and that this toxic material poisoned succeeding crops, especially if they were of the same kind. The former of these views has led to the practice of supplying minerals in the form of fertilizers, the latter view, directly, or indirectly through dire necessity, to diversified farming or crop rotation. Thus both lines of reasoning lead to important practical results in maintaining and increasing the fertility of our agricultural lands, but neither view can as yet be said to have passed the controversial stage through which all great truths must pass.

I do not desire on this occasion to dwell on these two lines of reasoning but rather to present some new soil facts which would seem to coördinate the apparently opposite views and to modify both, so that each becomes at least broad enough to be tolerant of the other. I refer especially to the accumulating store of information gained through modern chemical and biological research, as to the nature of that portion of the soil components, variously designated as organic matter, soil humus, humic acid, matiere noire, etc., and the various biochemical changes which are taking place in soils, and

ever giving rise to new compounds through decomposition or through synthesis, compounds which have distinct properties to influence plant growth or other biological activity in soils. With this knowledge comes the broader view that infertility in soils may as well be due to the presence of organic substances of biological origin inimical to proper plant development as to the absence of beneficial mineral elements. The existence of toxic organic compounds in soils has been amply shown by the researches of the Bureau of Soils into the nature of soil organic matter in infertile soils, and the properties of the isolated compounds in respect to their action on plants, so that the presence of toxic compounds in soils must be considered in connection with future work on the problems presented by infertile soils.

The scope of the investigation has necessarily been broader than a mere search for toxic substances and has included soil organic matter in general with the result that many organic compounds, both harmful and beneficial, have been found in the course of the investigation. With not a single soil compound isolated and identified a few years ago, those now definitely identified are as follows: Acrylic acid, adenine, agroceric acid, agrosterol, arginine, choline, creatinine, cytosine, dihydroxystearic acid, glycerides, guanine, hentriacontane, histidine, hypoxanthine, lignoceric acid, lysine, mannite, monohydroxystearic acid, nucleic acid, oxalic acid, paraffinic acid, pentosan, pentose, phytosterol, picoline carboxylic acid, resin, resin acids, resin esters, rhamnose, saccharic acid, salicylic aldehyde, succinic acid, trimethylamine, trithiobenzaldehyde, xanthine. A glance at the list will reveal the fact that most chemical classes are represented: hydrocarbons, acids and hydroxyacids, alcohols, aldehydes, esters, carbohydrates, hexone bases, purine bases, pyrimidine derivatives, sulphur compounds, etc. Most of them have been derived by biochemical changes taking place within the soil from the more complex compounds, from the fats, nucleoproteins, proteins, lecithins, etc. For instance, we may trace the complex nucleoprotein molecule through its various decompositions, first into protein and a complex nucleic acid which can further yield protein and nucleic acid. The protein resolves itself finally into such compounds as histidine, arginine, lysine, and possibly creatinine, all of which we have found in

soils. The nucleic acid may split off phosphoric acid, or a carbohydrate such as the pentose mentioned above, and one or the other of the soil compounds, xanthine, hypoxanthine, guanine, adenine, or cytosine. This illustration serves to make clear the close relation existing between the biochemical changes which take place in the soil and those which take place in the animal. Of course the ultimate origin of all these soil compounds are to be found in the plant and animal debris which finds its way into the soil, through maturing plant parts, roots, animal excreta, dead animals, or added in agricultural practice in organic fertilizers, such as dried blood, tankage, or in green crops plowed under. In addition to these sources which are extraneous to the soil, there is the synthetic action of the microorganisms which inhabit the soil, but much further work needs to be done on these biochemical changes in soils before their entire course is understood. The forces which are operative we have already shown to be those of lysis in general, especially hydrolysis, oxidation, reduction, and catalysis. The life forms which produce these forces in the soil are the bacteria, molds, protozoa, yeasts, and the higher plants. All these contribute to the biochemical changes in soils either through the above forces operative as enzymes, or through the synthesis of the organic soil constituents from simpler organic and inorganic material.

After isolation and identification the soil compounds are studied in respect to their action on growing plants, wheat being usually used as an indicator. At the same time the action of various fertilizer salts in diminishing or accentuating the action of the soil compounds on plants is determined. In this manner much information concerning the physiological action of the compounds, together with suggestions for its neutralization or elimination are obtained. Owing to lack of material not all of the substances isolated have been studied in this comprehensive way, but sufficient information has been obtained to show that among the above enumerated compounds there are some that are distinctly toxic to plants, others that are distinctly beneficial and still others that are either doubtful or inert in so far as direct physiological effects are concerned.

Among the substances harmful to plants, picoline carboxylic

acid, dihydroxystearic acid, oxalic acid, salicylic aldehyde and vanillin as having been found in unproductive soils should receive special mention. The first of these is only moderately toxic and has not been exhaustively studied, but is interesting in showing that nitrogen in such a compound is not only not available to plants, but that the compound containing it is unfavorable to plant development. The dihydroxystearic acid, on the other hand, has been more thoroughly studied and has been encountered in soils from many parts of the United States. It is a strong inhibitor of the normal processes of plant metabolism and destroys almost entirely the normal oxidizing power of plant roots, thus inhibiting root development and the power of absorption of mineral plant foods by the roots, even if present in the most available forms. Salicylic aldehyde is even more toxic than the dihydroxystearic acid and like salicylic acid it is a strong antiseptic, inhibiting the action of bacteria. This salicylic aldehyde was first discovered in a soil from the historic Mt. Vernon estate of George Washington, in the rose garden near the box hedge laid out by our first President. The remarkable fact in connection with this soil was that it contained a large amount of mannite, as much as 500 lbs. per acre. Although this is the only soil in which it has been found, the remarkable part was not in its being found there, for it can readily be produced by certain soil fungi, but rather that it should persist in the soil, when it is such an excellent medium for the development of bacteria. This sugar alcohol appeared to have no unfavorable effect on plants when it was tested in our greenhouse, but we were never able to make a good test because of the fact that the mannite solutions with the added fertilizer salts were such good media for the development of bacteria. The simultaneous presence of the salicylic aldehyde in the soil, and the fact that the latter was poisonous to higher plants, suggested therefore that the mannite in the soil was protected by the antiseptic action of the salicylic aldehyde. Experiments confirmed the antiseptic action of the salicylic aldehyde in preventing the decomposition of the above mannite solutions and the occurrence of the large quantity of mannite in this soil seems thereby explained. This case is particularly interesting as showing that soil compounds

affect the lower life of the soil as well as the higher plant life, and through these the entire biochemical processes, and furthermore that even if a compound like mannite be not toxic in itself, its very presence points to the fact that the soil is functioning abnormally, much as the presence of sugar or albumen in the urine, in themselves harmless, point to the fact that something is decidedly abnormal with the metabolism of the individual excreting them. The occurrence of certain compounds in soils likewise becomes a great agent in the diagnosis of soil troubles. The occurrence of the dihydroxystearic acid is a not uncertain indication of low and sluggish oxidation in the soil, whatever may be the cause that has brought this about, be it poor drainage, acidity, poor physical management of the soil or other soil abuse.

The poisonous oxalic acid has been encountered in only one instance thus far, and that in a soil containing much calcium carbonate. The amount, however, was so extremely large, nearly four tons of calcium oxalate per acre, that it is thought to play some part, even as the insoluble oxalate, in the peculiar failure of apple orchards in this soil. Experiments in greenhouse and orchard are still under way to determine these facts and I mention this case here only to point out the application of this type of investigation to problems where other means fail to diagnose the trouble. Another application of such work is in diagnosing the soil trouble which brings about the mysterious disease of the orange tree and fruit known as dieback with which growers have struggled for years with annual loss of thousands of dollars and which scientists now consider as a physiological disease, that is, one not caused by any pathological organisms extraneous to the plant itself. All facts point to the soil condition as the cause, but so inexplicable has been its behavior in respect to the soil that all ordinary means of chemical investigation have failed to lay bare the cause or causes. Typical dieback soils from Florida are now under investigation in our laboratories at Washington to determine in them such organic constituents as are possible by the methods so far developed. This work is meeting with success and a number of compounds have been isolated and these will be studied in regard to their effect on orange trees in

coöperation with Professor Floyd, of the Florida Experiment Station, to see whether they are responsible for this disease. Like the apple orchard experiment this work is still in progress and not sufficiently well advanced to discuss its practical significance but it serves to show the application of this type of biochemical investigation to certain great economic problems which confront many agricultural industries. Another of these harmful soil constituents is the pleasant smelling vanillin, a constituent of the vanilla bean, but also of many other plants, as shown in this and many other laboratories, and a compound which is somewhat harmful to wheat seedlings in solution cultures, chemically an aldehyde and thus a reducing agent capable of being oxidized and having its harmful properties reduced by such oxidizing fertilizers as nitrates. The properties of vanillin in regard to plant growth and its effect on root oxidation and the influence of fertilizer salts on its action, were determined on wheat in our laboratories several years ago in anticipation of the day when it would be found as a soil constituent. What is true in this respect of vanillin is also true of a number of other compounds but it is also equally true that some of the soil constituents isolated were not even remotely suspected of ever being found in soils, and in fact some of them have been previously only known as products of the chemist's laboratory, for instance, the saccharic acid, a laboratory oxidation product of sugars, or the trithiobenzaldehyde, previously only known as a sulphur substitution product of the laboratory.

While the subject of my talk limits me chiefly to a discussion of the soil substances which we have found to be harmful in our experiments, I must not omit in passing to speak of the many beneficial substances which have been discovered in soils as the result of these investigations, and which even more than the toxic substances, make clear the parallelism existing between the biochemistry of the soil and the biochemistry of the animal, because some of the compounds involved are absolutely identical. Among this list of beneficial soil compounds you will recognize common products of animal metabolism and digestive processes such as creatinine, found in the urine; histidine, arginine, lysine, products of protein digestion; xanthine,

hypoxanthine, products of animal fluids and nuclein degradation; and nucleic acid itself. These compounds increase plant growth and the results obtained would seem to show that the plant can use these compounds directly in building up the plant proteins and nucleins without further decomposition to ammonia and production of nitrites and nitrates.

Nor should I pass over the physiologically doubtful or inert soil substances without suggesting that these have a potentiality for good or bad, depending upon future changes brought about by oxidation, reduction, or other biochemical action resulting in the production of beneficial or harmful compounds. Nor should I fail to mention that many of these physiologically inert substances, as, for instance, the water insoluble resins, have a marked physical effect on the soil, often coating the soil grains and shielding the soil minerals as well as other organic substances from the solvent action of the soil waters, thus effectively interfering with an otherwise normal soil.

In speaking of the elimination and neutralization of toxic soil substances we must not lose sight of the fact now fairly well demonstrated by biochemical and biological researches that in every soil there is a balance of beneficial and harmful factors, soil fertility or infertility being the resultant of the two groups. As one or the other group of factors gains the ascendency, the fertility is raised or lowered, as the case may be. This balance is influenced by cultural treatment, such as draining, plowing, or otherwise working the soil, by the application of fertilizers, by liming, by the growth of plants, by crop rotation, etc. All of these factors affect the biology of the soil, the soil bacteria, the molds, and other microörganisms and through them the entire biochemical process in soils. Although the number of toxic soil constituents may be very large and probably but imperfectly represented by those we have thus far been able to isolate, it appears nevertheless significant that they are substances which have resulted from partial oxidation, but in their present form have reducing properties, and under favorable conditions are subject to further oxidation. They may be said to have resulted under imperfect conditions of oxidation or aeration whether this be the direct result of poor drainage, of soil acidity, or lack of lime, or poor cul-

tivation, or the growth of crops which do not promote deep root growth or active root oxidation. The studies which we have made on soils in respect to their ability to oxidize organic substances such as aloin has shown us that fertile soils are generally good oxidizers and infertile soils poor oxidizers. In soils that are good oxidizers the chances of having an undue accumulation or even formation of toxic substances are at a minimum, whereas in poor soils with low oxidizing power, with low vitality as it were to properly digest the organic refuse of previous growth, harmful substances result. The chief aim in improving unfertile soils should therefore be to build them up so that they will become good oxidizers and through this become strong virile soils. In the laboratory and greenhouse we have been able to observe the disappearance of toxic soil conditions by thorough aeration and exposure to air, by the action of lime, and by the influence exerted by fertilizers, especially the oxidizing fertilizers like sodium nitrate, or the catalytic influence of oxidizing substances like manganese. In the field the most useful agents are (1) better drainage, which promotes better aeration and increases the oxidation in the soil; (2) liming, which in addition to neutralizing acid tendencies, or combining with the substances to form insoluble or inert compounds, has also the effect of increasing the oxidation in the soil and in the plant roots as well as to have a physiological effect on the plant cells themselves which makes them more resistant to poisons in general; (3) crop rotation, which gives to the soil each year a different kind of organic debris, changing as it were, the normal food of the soil, from time to time, and furthermore necessitates different cultural methods and different fertilization systems, alternating cultivated crops with uncultivated crops, shallow rooted plants with deep rooted plants, grain crops with root crops, leguminous with non-leguminous crops, with the result that the biochemical changes in the soil, the digestion, the oxidation, the catalysis, of the soil, proceeds in a normal manner, the balance of soil factors being influenced in a favorable direction and a healthy normal soil results; and (4) fertilization, which is usually done with the motive of adding plant food, but which the more modern investigations in biological and biochemical fields are showing to be an

accessory to proper soil treatment because in addition to supplying needed plant nutrients they influence the microörganic life within the soil, because they influence the oxidation in the soil, the catalysis in the soil, the digestive processes in the soil, so that the biochemical processes are altered, the balance of factors influencing plant growth is changed, because they influence the oxidation of plant roots, and because, directly or indirectly, they effect the destruction, the neutralization, or prevent the formation of harmful substances. I have not considered here the mechanical composition of the soil particles, the big natural agencies which have operated to form soils, the location or topagraphy of the lands and the normal water capacity of soils, the origin of soils, or their relation to climate and rainfall, all of which factors influence soil type and contribute to make some soils naturally more fertile than others, naturally adapted for the growth, and sometimes the continuous growth of one crop, while unsuited to another, facts which must receive more and more attention in the future if we are to get the maximum returns from our soils. I am considering only the means which will tend to maintain or increase the fertility to a status normal to that kind of soil, to maintain it in a healthful, virile state.

The great question before scientific agriculture is not whether fertilizers are helpful, no more than modern medical science considers whether foods or medicines are helpful, but rather how can these be made more efficient, more certain in their action, more specific in their application to the needs of the soil. Soil students have in the past century contented themselves practically with a single factor of soil infertility, a not unimportant factor it must be admitted, but nevertheless one insufficient to explain all difficulties, namely, that of plant starvation, the question of lacking plant food. The studies have centered about the food of the plant while the surroundings, the home of the plant, the soil itself, has been virtually ignored, or given only minor consideration, except as a storehouse for plant food. Even in the more scientific work of the past decade in reference to bacteria, and other biological work, the production of plant food has been the motive of all study and all discussion is from the point of view of liberating potash, phosphate, or increasing the

quantity of nitrogen for the use of the plant. The biochemistry of these life forms in the soil, the multitudinous changes which they work have remained unstudied, only those facts were determined which influence the amount of the so-called plant food, ignoring even much material that is more truly plant food than the mineral substances and inorganic nitrogen compounds studied. In all lines of human activity the sanitary surroundings, the proper medical treatment and the proper nutrition of animals and of man, are receiving attention and the proper sanitary condition of the plant's home, the soil, will also receive more and more attention to prevent its harboring the germs of devastating plant diseases, and such decompositions or biochemical changes as produce substances inimical to the health of the plant, killing it or weakening it, so that it falls a ready prey to pathological organisms. In this campaign for a sanitary home for the plant, the above factors of better cultivation, better drainage, judicious liming, crop adaptation or crop rotation, and the use of fertilizers, will play an important part and as we learn more of the functions of the latter, their use will become more general and more specific so that we will be able to tell which will be the best suited for any particular soil condition or soil trouble, and in the future these will no doubt be modified and even augmented with other chemicals to meet special requirements. Some such special fertilizers are already on the market and more will follow, the only danger is that the advertising art will outstrip the science, which should be the basis for such changes.

The use of copper preparations in special orange fertilizers, or the use of manganese or other catalytic substances to promote oxidation in soils are illustrations of such use. The oxidation by manganese has received special attention in our laboratories and in the field and the conclusion seems warranted that such catalytic substances depend upon the form in which they are introduced or present in the soil and the form of the organic matter in the soil, which with the manganese forms activating combinations. In the field work its action is still uncertain so far as increased oxidation or increased crop growth is concerned. On poor soils, with acid tendencies, the results are doubtful, as will be shown by a forthcoming

bulletin on the field experiments over a period of five years on such an acid soil. A second period in which the soil will be limed to produce neutrality is now begun and it will be interesting to learn how the manganese will behave under this new condition.

That even the ordinary chemicals used in fertilizers, potash, phosphates, or nitrates can affect the harmful action of organic substances has already been incidentally alluded to in the preceding paragraphs. Our researches have shown that the harmful soil constituents, vanillin and dihydroxystearic acid have their poisonous effects greatly diminished or even entirely overcome by the addition of sodium nitrate, whereas their harmful characteristics remain unimpaired by the addition of phosphates or potash fertilizers. Nitrate is an oxidizing substance and we have shown root oxidation to be increased greatly by its use, whereas both vanillin and dihydroxystearic acid decrease root oxidation and are themselves capable of being oxidized. The effect of nitrate and these two substances are therefore opposed to each other and thus neutralize each other, or, what is more probable, neutralize their effects. The substance, quinone, on the other hand has its poisonous action reduced by potash salts, not by nitrate nor phosphate. Quinone is an active oxidizing substance, while potash reduces root oxidation thus again showing that these two substances antagonize each other in their effects. The substance cumarin we have found to be very toxic to plants. This toxicity is not diminished by nitrate nor by potash, as was the case respectively with the preceding substances, but its action was most remarkably overcome by the addition of phosphate and it seemed to make no difference in what form the phosphate was used, whether it was as a calcium salt or as a sodium salt, or as the monobasic, dibasic, or tribasic salt.

I have mentioned these illustrations of specific fertilizer action to show the possibilities of the future in adapting fertilizer treatment to meet the specific needs of the soil based upon a perfectly rational basis of soil treatment to meet the requirements of specific crops or the requirements of plants suffering from unhealthy, insanitary soil conditions, which involve the presence of biochemical transformations resulting in compounds detrimental to the best plant development.

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GEOLOGY OF THE REGION ABOUT NATAL, RIO GRANDE DO NORTE, BRAZIL.

(PLATES XV.–XXII.)

BY OLAF PITT JENKINS.

(*Received May 29, 1913.*)

INTRODUCTION.

The state of Rio Grande do Norte is one of the smallest in Brazil; it has an area of 57,485 square kilometers, and lies wholly within the tropics. The climate, topography and geology of this state may be taken as a type of the geology of the northeastern coast of Brazil.

Topographically the region is one of rather low relief, the climate is semi-arid, and in places the soil is thin. The general geology is simple, consisting of an old series of crystalline rocks, probably of Archean age, over and upon which rests a coastal belt of Cretaceous or Tertiary sediments having a width of about thirty kilometers. There are some mountains of fair size in the interior, but they are nearly all of granites or other crystalline rocks. None of these mountains lie within the area discussed in the present paper.

In 1909 I published in the *Bulletin of the Geological Society of America* a paper on the geology of the Northeastern Coast of

Brazil that included all that was then known of the geology of the coast of Rio Grande do Norte from Natal to the southern edge of the state. That paper contained a sketch map showing the coastal belt of sedimentary rocks.

The work of Mr. Jenkins, done in 1911, has added much to our knowledge of the region, especially to the north of Natal, and it has definitely located the landward margin of the sedimentary beds.

It has also disclosed an unconformity in the sedimentary beds that seems likely to clear up the long standing question in regard to the existence of the break between the Cretaceous and the Tertiary in this part of South America. Some of my own geological observations made in 1911 have been incorporated in Mr. Jenkins' paper, while specimens of crystalline rocks from near Baixa Verde, examined microscopically and described by Mr. Jenkins, were collected by Mr. Earl Leib another member of the expedition.

J. C. Branner,

Director of the Stanford Expedition to Brazil.

Stanford University, California,
May 6, 1913.

Introductory.

In the summer of 1911 the Stanford Expedition to Brazil made its headquarters for six weeks at Natal, in the state of Rio Grande do Norte, 5° 45′ south latitude, 35° 12′ west longitude. During this time most of the members of the party were engaged in collecting zoölogical material. Occasional inland trips were made which gave means for determination of geological data. These trips were along three lines, each of which went far enough into the interior, about forty or fifty kilometers from the coast, to reach the crystalline series of rocks:

1. To the northwest by railroad—"Estrada de Ferro Central do Rio Grande do Norte"—to Taipú and Baixa Verde.

2. To the south and southwest by the "Great Western Railway of Brazil," which extends for many kilometers down the coast.

3. To the west by boat up the Rio Jundiahy to Macahyba.

The ways by rail afforded the gathering of geological data by notes taken from the car windows, and by material collected at the various places where the train stopped. At certain points the party remained for several days and from these points horseback trips and walks gave data of more detailed character. These side trips were made around the towns of Taipú, Itapasaroca, Ceará-Mirim, and Extremoz.

A horseback trip from Carnahubinha to Macahyba and back into the interior, followed one of the contacts and gave familiarity with the general character of the country.

Thus the map was compiled from compass traverses, notebook sketches, railroad surveys, hydrographic charts, and the map of the region made by Crandall and Williams to the scale of 1 to 1,000,000.

Topographic Relief.

The Coast.

The vast stretches of sand are the most striking feature in the region about Natal and the northeastern coast of Brazil. The wind blows constantly up the coast to the northwest, driving the sand before it, filling up the stream mouths, banking against the low shrubs, sometimes planted by the people along the coast, forming a great range of sand-hills parallel to the coast. It is swept back by diverging currents over the low interior country for many kilometers covering up the soil and rocks, filling up the broad valleys, and forming long parallel sand-dunes all pointing to the northwest.

Underlying sandstones outcrop along the coast at various points. They form generally perpendicular cliffs from a few feet to about seventy-five feet in height as those of Barreiras do Inferno. These sandstones contain iron which is concentrated in certain places, hardening them into limonitic rocks that ring like steel when struck with the hammer. Sometimes all the pebbles of a portion of a beach are cemented together in this manner, forming a prominent point along the coast. These low points of dark, red-brown rocks and parti-colored cliffs of sandstone break the continuity of the white sand beaches. The wind, sweeping up the coast, banks the

sand at the points, forming a smooth straight shore line up to the south side, and leaving a little cove on the north side. Tall cocoanut palms may grow along the shores of this cove, waving over a tiny fishing village and a little church. The fishermen can here embark in their *jangadas* with greater ease than out on the windy south side of the point. Usually into such a cove a stream flows, if not, the people get their water by digging into the sand of the coast and a bubbling supply of sweet water is easily obtained. Sometimes one may see fresh water coming up through the sand right where the waves wash.

The sand is blown into the river mouths and tends to fill up their south sides, causing the streams to cut into their northern banks, where the sand is being swept away. Thus many of the streams turn, just before reaching the sea, and flow northward as they enter the sea. A view of a river's mouth from a vessel at sea shows a high range of sand-dunes on the south side, while to the north the country is low and rises gradually farther up the coast, where it culminates at another river mouth.

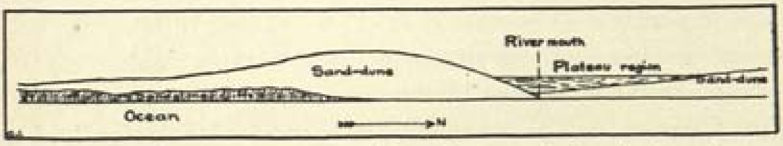


FIG. 1. A view from a steamer towards a river mouth, showing how the sand piles up at the south side of the stream.

There is often a hardened sand-beach in front of the mouth of such a stream, lying in a straight line parallel to the shore, where the fresh water meets the sea water. These stone reefs[1] have the general appearance of an ordinary sand bar, but they are hardened almost to a quartzite, and are difficult to break with the hammer. They contain white quartz sand and marine shells now found along the beaches. Often these stone reefs are found with no apparent stream behind them, but if one goes farther back into the country one may find an abandoned stream channel which formerly had an outlet behind the stone reef.

[1] J. C. Branner, "The Stone Reefs of Brazil," *Bul. Mus. Comp. Zool.*, Geol. Ser., VII., Cambridge, 1904.

The sea is shallow along the coast, and one sees this especially when watching the natives setting their *jangadas* afloat by pushing them along the wide, gently sloping beaches. Often at the end of

FIG. 2. General cross-section of the sandstone reef at Natal, Rio Grande do Norte.

one of the prominent points, as that of Pirangý, it may be noticed at low tide that the rocks extend for a considerable distance and then an organic reef, containing corals and other marine animals, continues far out to sea; forming a flat shelf for some distance. These organic reefs do not occur near shore, for the waves are full of sand, scooped up from the shallow bottom. The ships cannot come near shore, except through certain channels as that of Natal, where the animals that make up the reefs cannot live on account of the fresh water from the river.

The Valleys.—The most striking feature about the river valleys is their extreme width in comparison to their shallow depth. A small stream like the Rio Ceará-Mirim may flow through a valley two and a half kilometers wide not much more than fifteen meters below the surrounding region. The banks which fringe the wide valleys expose red iron-sandstones, covered with sand or a sandy soil. The valley alluvium is a darker black sandy deposit. The whole floor of the valley is flat, with a sluggish stream flowing down its center, bordered by swamps. The natives, whose mud houses are scattered or clustered in villages along its low sides, use it to advantage and cover most of the valley with their banana, corn, cotton, and sugar-cane fields. In some places, such as Ceará-Mirim, the region is very fertile and a growth of shrubs, trees and *carnahuba* palms covers the valley.

The valley, on the side of which Natal is situated, is about six kilometers wide, but most of this territory is silted up by mangrove swamps. The sea enters it and at high tide flows up to Macahyba

at a distance of about thirty-five kilometers, and returns at low tide. This action is utilized by the people who travel up and down the river only by tides. The present silting up of this great channel and many others like it is extremely interesting because it shows a sunken coast. The sea has intruded into the stream channels and later it has been driven out by the deposition of silt.

The Plateau Region.

The surrounding region is a low, sandy, gently rolling plateau covered with shrubs not much over two and a half meters in height. The small scrubby rubber tree is its typical plant. Farther back into the interior the hills become a more prominent topographic feature,

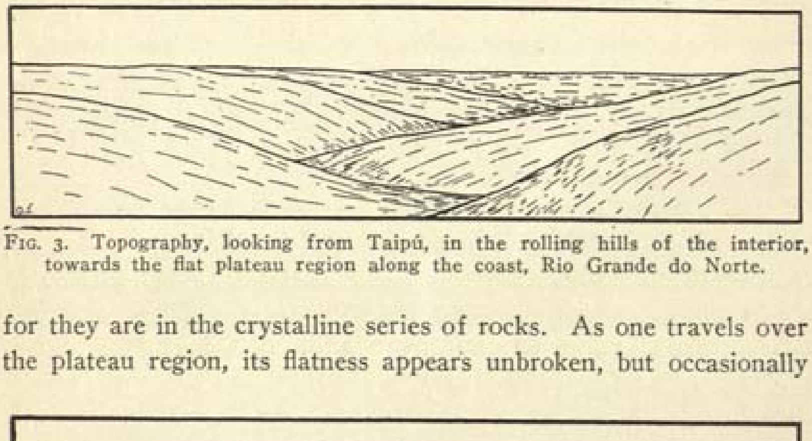


FIG. 3. Topography, looking from Taipú, in the rolling hills of the interior, towards the flat plateau region along the coast, Rio Grande do Norte.

for they are in the crystalline series of rocks. As one travels over the plateau region, its flatness appears unbroken, but occasionally

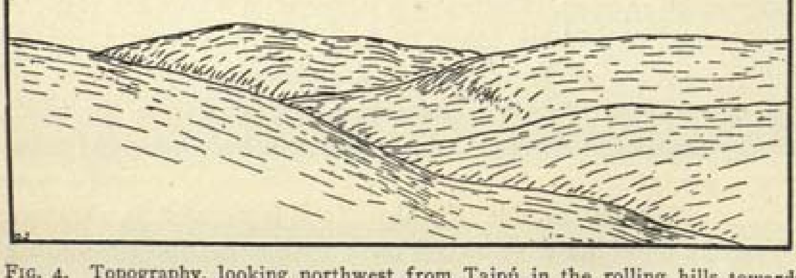


FIG. 4. Topography, looking northwest from Taipú in the rolling hills towards the higher, interior country, Rio Grande do Norte.

one comes upon the border of a wide valley with unexpected groves of *carnahuba* palms, fields of sugar-cane and bananas. A village with its quaint church, set on the upland, looks out on the fertile area while all the surrounding country is as dry and arid as a desert.

The farther one goes into the interior the more arid the country gets. The river valleys diminish rapidly in width, and low hills of crystalline rocks are rounded almost to flatness by age and decomposition. The granites tend to stand out as huge rounded domes, carved and grooved from weathering, while the gneisses and schists form the general base-level plain. The whole region reminds one of the deserts of Arizona with its dry, warm atmosphere, its cacti and desert shrubs, and its lack of water.

It is in a belt about ten or twenty kilometers wide along the coast that the rains have their most decided effect. This region is covered with numerous small fresh-water lakes. Some of them are connected with the ocean and some are not. In times of great rains they overflow and connect with each other. In times of drought some of them dry up completely, as Logoa Secca near Extremoz, a mere depression now which is said to have been full of water forty years ago. Often the lakes seem to have no outlet nor inlet, but if they are examined more closely they are found to be fed by springs occurring along the border just between the impervious clayey iron-sandstones beneath, and the loose wind-blown sand-dunes above. This was especially noticed in the case of Logoa Bom Fim, about thirty-eight kilometers south of Natal. Villages are scattered along the borders of these lakes and each has its cocoa-palm grove. The people are very poor and live on the little they are able to raise and the fish which are caught in the lakes. Other lakes are formed in the river valleys dammed in at the mouths by sand bars on the seacoast. These regions are the most fertile of all. Paparý is a typical example of such a place.

Areal Distribution of the Formations.

The sketch map of the region about Natal, given at the end of this paper, shows best the general distribution of the formations.

In the interior the rocks are crystalline: granites, gneisses, schists, shales, quartzites, and various forms of intrusive dikes. At Macahyba an engineer, who had been far back into the country, reported marble at a distance of about one hundred and sixty kilometers from the coast. This marble was said to have been like that found near Quixadá in Ceará, at the same elevation and relative location. The granitic rocks which are nearest the coast, in the region which this paper deals, occur at Macahyba, for here the river cuts deeply through the sedimentaries and exposes the older series.

Overlying the crystalline series are beds of fossiliferous limestone, lying almost horizontally, or dipping about 5° southeast, towards the coast, in layers of a few inches to a foot or more in thickness. This series is not well exposed. The principal localities for the exposures are at the railway cuts and at the quarries made in the limestones where they come to the surface along the sides of the valleys. Following along the contact of the granites with the sedimentaries one may find occasional indications of limestone on the surface. There seems to be a belt of this limestone, left from the great erosion the country has undergone, about ten kilometers in width. A few pebbles of limestone were found on the surface not far from Taipú, thus indicating a greater extent of the limestones in previous ages.

Unconformably overlying the limestones occurs an unfossiliferous iron-sandstone and clay series of generally unconsolidated material. The beds of this series are hard to distinguish, but they also seem to lie horizontal or to dip gently towards the coast. They extend in a belt about thirty kilometers in width along the coast. They are best exposed as sea-cliffs.

The wide river valleys contain a deep deposit of alluvium. This is an important factor in the geology of the country for these deposits are found to contain marine shells, showing the valleys were once filled with water from the sea, and later completely silted up. This process of silting-up is at present at work in some rivers as Rio Jundiahy and Rio Potengý, where it occurs about twenty-five kilometers inland. It is a mark of a submerged coast.

Over all the other formations a vast amount of sand is at present

being deposited along the coast, blown inland by the wind. The sand tends to fill up the river systems, for they are the lowest places. In time of drought the sand sometimes is able to gain complete control over some of the streams, stopping them up entirely. In time of great floods the water clears its channel again. A good example of damming by sand is the valley of Extremoz, where

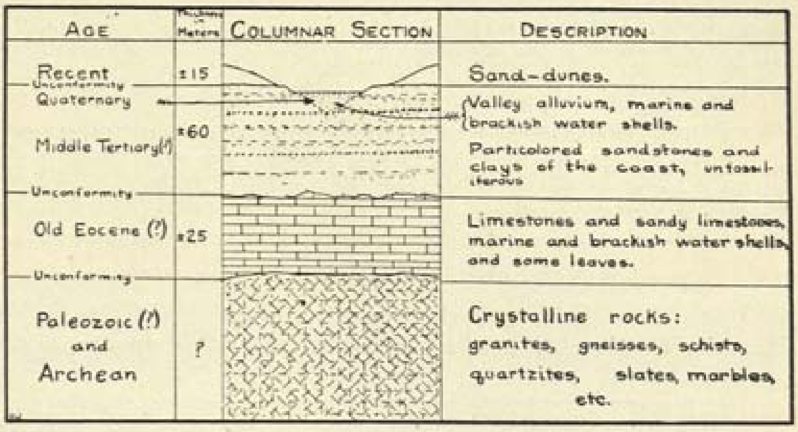


FIG. 5.

sand-dunes are heaped in the valley in longitudinal rows, while at its mouth is a great sand bank, twenty-five to thirty meters in height, lying across it at right angles. About fourteen kilometers inland Lake Extremoz lies in the forks of the old river channel, dammed in by this wind-blown intrusion.

Description of the Contacts.

The limestones lie unconformably on top of the old crystalline series. The contact was plainly seen at Alvoredo, about five kilometers north of Macahyba, in the bed of the Potengý River.

The sandstone and clay series lies unconformably on top of the limestones. At Jacoca, five kilometers southwest of Ceará-Mirim, the contact was observed in the limestone quarries. This showed the fossiliferous limestones in clearly defined beds, six inches or a foot thick, lying horizontally, with the sandstones rest-

ing unconformably on top. This unconformable contact is distinctly marked at these quarries and was carefully studied; photo-

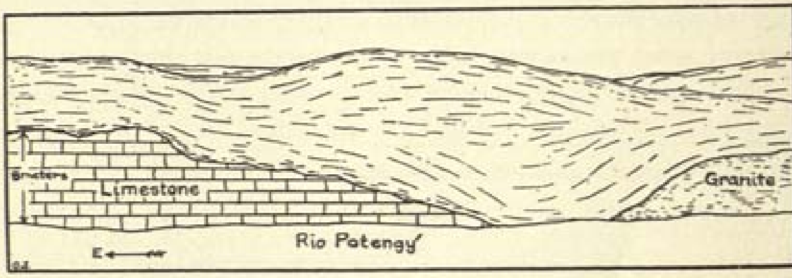


FIG. 6. An exposure along Rio Potengý showing the contact between the horizontal, fossiliferous limestones and the granites. Looking south, near Alvaredo, Rio Grande do Norte.

graphs were taken and material collected. At the point of contact the sandstone is very black, probably carrying manganese. Above this the sandstone has a soft white character, while on top lie the

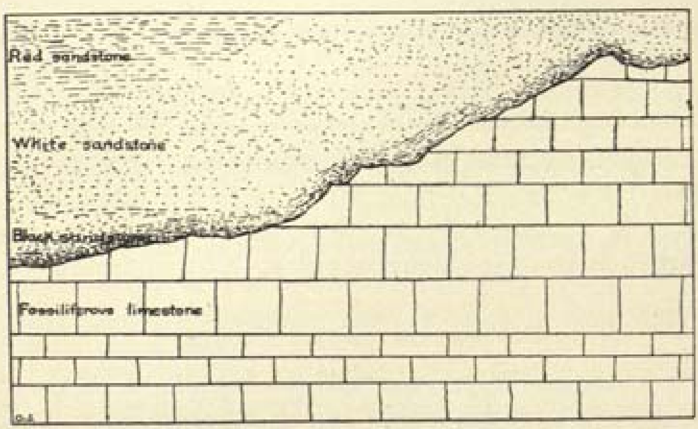


FIG. 7. Diagram made from a photograph of the unconformity between the fossiliferous limestones and the sandstone and clay series as exposed in a quarry at Jacoca, five kilometers southwest of Ceará-Mirim, Rio Grande do Norte.

red iron-stained rocks so common over the country. On the surface of the ground are loose boulders of the iron-rock. The bedding of the sandstone is not very clear, as in most localities, but has the general appearance of being horizontal.

The relation of the sand-dunes to the sandstone is clearly defined along the sea-cliffs. The older æolian deposits of sand lie cross-bedded on top of the horizontally bedded sandstone and clay series. Above these are blown newly formed sand-dunes.

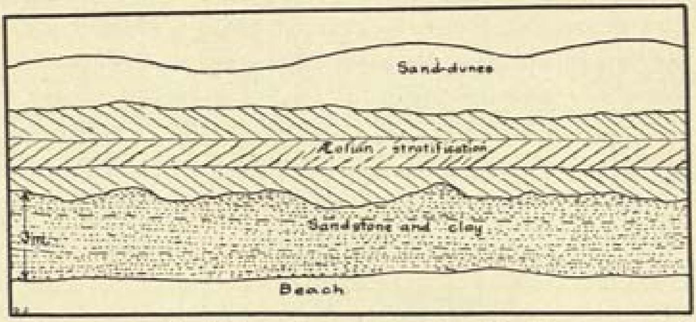


FIG. 8. Diagram of the bluffs at Ponte Negra, Rio Grande do Norte, showing the old æolian stratification with the newly formed sand-dunes lying on top.

The alluvial deposits are extensive, filling the wide river channels.

DESCRIPTION OF THE FORMATIONS.

The formations are described in this paper in the following order:

1. The crystalline rocks, probably Archean.
2. The limestones, of late Cretaceous or early Tertiary age.
3. The iron-sandstones and clays, which are later than the limestones.
4. The alluvial deposits.
5. The sand-dunes.

The Crystalline Rocks.

The railroad extends twenty-eight kilometers west of Taipú to Baixa Verde. The rocks of this region are crystalline, and a study was made of them here. Beyond Baixa Verde one or two kilometers, new railway cuts expose fresh specimens of these rocks, showing something of their general relation to each other. This part of the paper has been taken freely from the notes of Dr. J. C. Branner and Mr. E. Leib. Slides, made from the rocks collected, have been studied and the following report is submitted.

Decomposition has had a marked effect in leveling down this region, so that the natural exposures are only in the shape of flat bosses and exfoliated boulders. Mound-shaped hills, as that of Torreão Peak, which is about seventy meters high, lying three or four kilometers northwest of Baixa Verde, are composed of granitic rocks. On their surface are scattered great boulders of exfoliation, while at their base are bare, flat exposures of other crystalline rocks, giving to the whole the appearance of glaciation.

In all the railway cuts it was noticed that dikes of granites and pegmatites cut through micaceous schists. These dikes vary in width from one to thirty meters, sometimes following the plane of schistosity and sometimes cutting across it. Often one dike inter-

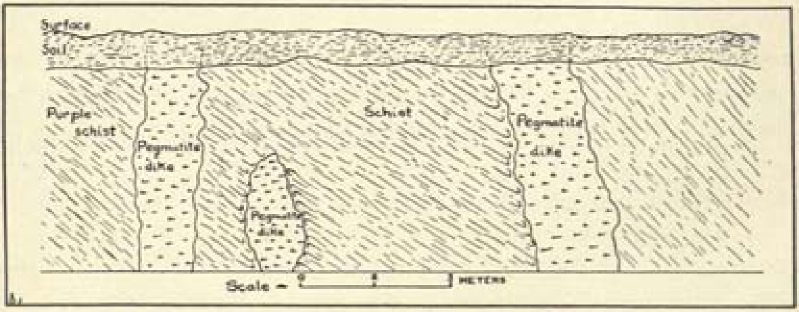


FIG. 9. Diagram of railway cut near Baixa Verde, Rio Grande do Norte, showing how the dikes intersect the schists and how the topography is unaffected by these.

sects another. These dikes and schists do not show in the topography; all are eroded and decomposed to the same surface level.

The following are descriptions of the rocks collected.

Quartzitic Arkose.—This specimen was collected near Taipú, kilometer 53. It outcrops in the region of dikes and schists. The rock is a medium-grained quartzitic arkose containing some minute cavities. Under the microscope the grains show that they are irregular in size and angular to subangular in shape. They are principally fragments of quartz, plagioclase, microcline, and orthoclase, all cemented firmly by opal. Chalcedony occurs as a secondary mineral, filling the minute cavities.

Quartz-Biotite Schist.—This was found at kilometer 49.5 near the place where the railroad crosses the Ceará-Mirim River, not far from Taipú. The rock is dark-colored, hard, rather fine-grained, containing quartz and biotite in great abundance. Its general appearance indicates that it may have been derived from some old sedimentary series. A slide shows quartz and biotite to be abundant as cemented grains. The feldspars are cloudy and hard to distinguish. Magnetite is scattered through the rock. There is some hornblende and tourmaline present.

Biotite-Schists.—In the cuts west of Baixa Verde granites and pegmatites cut through biotite-schists. Fresh specimens of these schists have a shiny, black or purple color. When weathered a little, the schists turn a brownish tint. In one specimen collected at the sixth cut beyond Baixa Verde, the following minerals appear in the slide: biotite in great abundance, quartz rather prominent, a considerable quantity of plagioclase and orthoclase, only scattering amounts of apatite and magnetite, and some garnet. Another specimen of this biotite-schist, which is partly weathered, shows some sillimanite.

Granite-Aplite.—A specimen from a dike cutting through the biotite-schists in the fifth cut west of Baixa Verde is a medium-grained, pinkish-white granite-aplite. Quartz grains are distinct. Muscovite and biotite are easily recognized in the hand specimen. With the microscope the following minerals were found: orthoclase and quartz are abundant; plagioclase and microcline are rather prominent; there is a quantity of titanite; both muscovite and biotite are present; some garnets and specks of magnetite are scattered through the rock.

Granite-Pegmatite.—Occurring as dikes, breaking through the biotite-schists, are granite-pegmatites. Some of them are graphic granites, and in some the quartz is scattered through irregularly. All of them are a light pinkish, decomposing to an almost whitish color, the feldspars changing over to sericite. A slide shows the following minerals: orthoclase, plagioclase, and quartz in abundance; microcline, rather prominent; biotite in patches; and tourmaline of a very dark variety. In one pegmatite there occurs a vein of red-

brown chalcedony. This may indicate that the schists were derived from old sedimentary rocks.

Granites.—The larger dikes which cut through the schists are usually granites. These rocks are medium-grained with a pinkish-gray color due to pink color of the feldspars. In one specimen the following minerals are in the slides: quartz, plagioclase, and orthoclase in great abundance; hornblende and magnetite prominent; titanite, garnet, and pyrite in smaller amounts. Other specimens from one of the larger dikes show a quantity of microcline and in addition to the other minerals zircon and apatite. In a specimen which came from a decomposed portion of the granites, sericite is prominent. The feldspars decompose leaving the mica flakes and the quartz grains prominent at the surface.

Log of Well at Baixa Verde, Rio Grande do Norte.

The following is a log of a well with a six and three-fourths inch bore taken at Baixa Verde, Rio Grande do Norte, at kilometer 84, elevation 162 meters.

	At — meters.
Gneiss	5
Dark granitic schist	10
Granitic rock, hard	15
Gneissoid granite	18
Schist	24
Fresh, hard granite, pinkish	39
Gneissoid granite, with dark streaks	43
Hard, gneissoid granite, pinkish	45
Greatest depth reached	46

From the above well, bored in crystalline rocks, it is clear that the gneisses, schists, and granites are intermixed and intergrade. This is typical of the way in which they occur in this country,—first one and then the other, with perfect gradation.

The Limestones.

General Description.—The limestones vary in color from light yellow to pure white. Some of the beds are bluish in appearance

and are hard and siliceous. Other beds are softer and limy, scattered through with sand grains, while others are almost sandstones. At the quarries, where the beds can best be studied, the more siliceous parts are cast away and the limy portions put in the kiln. The limestones usually show indications of fossils by small cavities and poor casts of shells and plants, but actual remains of animals themselves were not found. Metasomatic replacement of the shells by other minerals was not found to occur, although large irregular cavities give place for the deposition of silica in the form of quartz geodes.

A slide of the limestone obtained near Itapasaroca was studied. The following minerals in irregular grains were found in it: quartz orthoclase, microcline, and mica (biotite and also probably muscovite). The main part of the rock is a fine-grained carbonate containing both calcite and dolomite. Chemical tests showed some portions of the rock to be more dolomitic than others. It may be called a *magnesian limestone.*

Detailed Description.—The following are the principal localities studied where the limestone series is exposed in cuts:

1. Itapasaroca,—railway cut at kilometer 45, exposing limestone beds containing fossil casts of shells and plants.

2. Ceará-Mirim,—a quarry near kilometer 35. Limestone is exposed but there are no fossils.

3. Jacoca,—four kilometers southwest of Ceará-Mirim two quarries expose fossiliferous limestone beds. Here the line of the unconformable contact with the red-sandstones may be definitely traced.

4. Masaranduba,—fifteen kilometers north of Macahyba. A quarry is on the bank of one of the inlets to Lagoa Extremoz. There were only bare traces of fossils in the limestone beds.

5. Desterro,—seven kilometers north of Macahyba. A quarry in sandy fossiliferous limestone.

6. Alvoredo,—exposure on the bank of Rio Potengý, three kilometers north of Macahyba. Here limestone, with faint traces of fossils, lies directly on top of the granite, also exposed in the stream.

All expose practically horizontal beds, which have the general tendency to dip towards the ocean to the southeast. These lime-

stones are all obviously in the same horizon. Although each locality seems to have its own specific character and fossils, yet they all are more or less similar and are probably different facies of the same horizon.

Itapasaroca.

Half a kilometer beyond Itapasaroca, at kilometer 45, the railroad cuts through beds of limestone. This cut exposes four or five meters of the series. In the material thrown out of the cut, impressions of shells are abundant. In some of the rocks figures of plants, such as palms, occur. No good fossils could be found, but there is an abundance of material. The rock is a light or buff color. It occurs in beds of a foot or six inches in thickness. The strata stands almost horizontal or dipping slightly towards the sea to the southeast. In this exposure some of the beds have been slightly compressed into waves of about a meter in height. Beyond this cut is the old valley of Ceará-Mirim, and on its opposite side are the crystalline rocks, at a lower level than the limestones.

Ceará-Mirim.

About two hundred meters up the railroad from kilometer 35, near the town of Ceará-Mirim, a lime kiln is situated on the south side of the railroad track. One hundred meters or so up the hill from this is a limestone quarry. The hill forms the bank of the valley of Rio Ceará-Mirim, and the railroad skirts its edge. The beds at the quarry are practically horizontal, four meters being exposed in the cut which lies about 28 meters above the railroad track, whose elevation at Ceará-Mirim station, not far off, is 31.5 meters. Thus these beds lie about 60 meters above sea level. The material of the beds is very hard and limy. The fossils, which formerly must have been in this rock, have been completely obliterated by circulating waters. It was noticed at this quarry that the decomposition of the beds was aided by the action of roots of the shrubs, which opened cracks in the limestone allowing surface waters to pass readily downward. These waters carry with them iron from the sandstones above and deposit it in the cracks, leaving the

white limestones marked with streaks of red-brown. The hill above these beds is covered with thick scrubby vegetation. The soil is red and sandy, and lumps of the red iron-sandstone are scattered over the surface, showing that the sandstone beds lie above the limestones.

Jacoca.

Four kilometers southwest of Ceará-Mirim is situated the village of Jacoca in the valley of one of the inlets of Lagoa Extremoz. On the northern bank of the valley are two limestone quarries. These expose about four meters of limestone beds overlain, in certain places, by as many meters of the red-sandstones. The contact between these two series of rocks is irregular and unconformable. Each limestone bed is about a third of a meter in thickness, making a total of twelve beds. These vary in their content of lime and silica. Poor impressions of fossil shells are still left in the rock. The material is almost pure white in color and is a magnesian limestone with sand grains scattered through it. The contact line is irregular and shows that the limestones once underwent the reduction of erosion before the sandstones were laid on top. Between these beds and the sandstones is an area of black material which is probably a deposition of manganese. Above these are whiter sandstones of soft character, and still higher up are the red sandstones, characteristic of this latter series. On the surface of the ground are scattered boulders of the red iron-rock.

Masaranduba.

The village of Masaranduba lies in the valley of Rio Guargirú, an inlet to Lagoa Extremoz, on a road which leads from Macahyba to Ceará-Mirim, about half way between these two cities. One kilometer east of Masaranduba is a limestone quarry situated on the bank of the valley. The beds in this place are practically horizontal and unaltered. The exposure is four or five meters high. The material is of very pure limestone. It is white, and almost devoid of any fossil remains. On the hill above are loose pebbles of both limestone and iron sandstone.

Desterro.

On the northern side of the broad valley of Potengý, north of Macahyba and near the place of Desterro, are some surface indications of limestone. Holes, a meter in depth, have been dug in prospecting for limestone. The material in these dug-outs is a yellow sandy limestone containing fossils, evidently in the same series as the other limestones.

Alvoredo.

On the southern side of the valley of Potengý, near Alvoredo and north of Macahyba, where the river cuts into its bank, is an exposure of about eight meters of limestone beds. These are horizontal. The material is the same as in the other localities with more sand and with more fossil impressions. Up the river, thirty meters or so, is a granite mass in place, standing about five meters high. Although bushes and soil hide the actual contact of the limestones with the granite, yet it was clear that the beds lapped directly on top of the crystalline rocks.

Fossils from the Limestones in the Region About Natal, Rio Grande do Norte.

The material collected from the fossil localities of the limestones in the region about Natal, Rio Grande do Norte, is exceedingly poor. Only casts and impressions could be found. In all they consisted of about a dozen different species of marine or brackish water shells, one questionable crustacean, and some plants, chiefly palm leaves. The limestones contained, in most cases, just enough sand grains to ruin the detailed character of the impressions. There were no definite horizon-marking fossils, but they all have the general appearance of being Tertiary, probably in the lower part of the series.[2]

[2] A collection of the fossils from the Rio Grande do Norte limestones was sent to Professor Gilbert D. Harris, of Cornell University, for examination, and he writes as follows of it under date of December 20, 1912: "Many of your specimens I judge belong to undescribed forms. Of the generic types I see none that might not possibly be anywhere from Cretaceous to recent, except perhaps the fragmentary impress of an Arca. None appear to

This material looks very much like that collected at Ponta de Pedras, which is supposed to be Eocene.[3]

The only fossil which is common to both these localities is *Cardium soaresanum* Rathbun.

The general character of the beds shows them to have been deposited in an estuary. This indicates that such a condition existed then as now along the coast of Brazil, *i. e.*, a sunken coast.

CARDIUM (CRIOCARDIUM) SOARESANUM Rathbun.

(Plate XX., Figs. 2 and 2*a*.)

Cardium soaresanum Rathbun. *Proc. Bost. Soc. Nat. Hist.*, Vol. XVII., Rathbun, "Cretaceous Lamellibranchs of Pernambuco, Brazil," pp. 253–255, 1874.

Cardium (*Criocardium*) *soaresanum* Rathbun. Extract from *Archivos do Museu Nacional do Rio de Janeiro*, Vol. VII., C. A. White, "Cretaceous Paleontology of Brazil," p. 90, Pl. VI., Fig. 6, 7, 8, Wash. 1888.

Cardium (*Criocardium*) *soaresanum* Rathbun. *Bull. Geol. Soc. Am.*, Vol. 13, p. 47, J. C. Branner, "Geology of the Northeast Coast of Brazil," 1902.

This is the only species that may be identified in all the material collected from the limestones of the region about Natal, Rio Grande do Norte. Numerous casts were found in every fossil locality and are easily recognized by the fine radial ribs, about 22 in number,

be distinctly Cretaceous unless the fragmentary impresses of a broadly turreted form showing some peculiar internal lirations should prove with other material to be a true Nerinæa. The fauna bears some resemblance in its little Chione forms to the Maria Farinha fauna, and though evidently representing a phase I am unacquainted with, I should be inclined to regard it as old Eocene. Still, as I said before there is not a single characteristic form wherewith to prove this statement."

The *Journal of the Academy of Natural Sciences of Philadelphia*, Vol. XV., lately published, has a paper on some fossils found at Trinidad in the northern part of South America. It settles the age of the Maria Farinha, Olinda and Ponte de Pedras beds definitely as Midway Eocene (pp. 32–33). The beds at Itapasaroca look precisely like those of the Midway Eocene beds, and each contains *Cardium soaresanum* Rathbun.

[3] J. C. Branner, "Geology of the Northeast Coast of Brazil," *Bull. Geol. Soc. Am.*, Vol. 13, p. 47, 1902.

each ornamented with minute points on its ridge. The specimens are small, about 12 mm. in height and width, and the thickness of the two valves is 6 or 7 mm. Inside casts are smooth and may be confused with the impressions of the sculptured outside.

CORBULA (?) sp. ind.

(Plate XX., Fig. 1.)

This Corbula-like form is not like that recorded from Ponta de Pedras. Most of the specimens were 12 or 15 mm. long and 8 or 9 mm. high, but one specimen is twice that size. The beak is situated about a third the total length from the posterior end. No radial ribs appear in the impressions, but the lines of growth are very plain, standing out in marked relief. At the anterior end there is a raised portion, almost a ridge, running to the beak. The total angle made by the shell, taking the beak as the vertex, is approximately 120°.

This form is easily recognized by its smooth, even form and the distinct concentric lines of growth. It is abundant at the exposure in the railway cut near Itapasaroca, Rio Grande do Norte.

CERITHIUM (?) MIRIMENSE Jenkins, new species.

(Plate XX., Figs. 8 and 8a.)

Many casts and impressions of a *Cerithium*-like form were found at the railroad cut near Itapasaroca, Rio Grande do Norte. The maximum height of the shell is nearly 15 mm. and the width of the lower part is 6 or 7 mm. The angle of the spire is 40° to 45°. Four or five ridges stand out on each half volution, running in the same direction as the spire, and alternate with the ridges on the adjoining volution. Spiral lines, 6 or 7, to each volution, run over the ridges and around the shell, following the volutions, and dividing the ridges into a row of little knobs. There are 6 or 7 volutions, which decrease rapidly in size as they approach the top of the spire. The aperture was not well preserved in any of the specimens collected. In one or two cases it looks as if it were oval-shaped. There is no sign of an extended canal.

This species is easily recognized by its very convex shape and the distinct sculpturing which is on its sides. Delicately ornamented cup-shaped impressions, left in the finer siliceous parts of the limestones, may be easily observed.

CERITHIUM (?) sp. ind.

(Plate XX., Fig. 4.)

At the locality near Desterro were found impressions of a *Cerithium*-like form unlike those found at the other localities. Length, 10 mm. to 12 mm.; width of last volution, 3 or 4 mm.; angle of the spire, approximately 25°. The volutions are about 8 in number, each convex in profile, and ornamented with spiral, slightly dotted lines following around the volutions. The aperture was not preserved in any of the specimens.

TURRITELLA (?) JACOQUEA Jenkins, new species.

(Plate XX., Figs. 7 and 7*a*.)

A broadly turreted form. The length is 25 or 30 mm. The width of the last volution is 12 or 15 mm. There are 8 or 9 volutions on the spire which comes to an angle of approximately 40°. Each volution is slightly convex in profile. The ornamentation is not distinctly visible on such poor material. There may be some sort of ornamentation following the center of the volution.

Many poor casts and impressions of these shells were found in the sandy limestones of the quarries at Jacoca, four kilometers southwest of Ceará-Mirim, Rio Grande do Norte. Inside casts show a double spiral coil following the volutions.

It is difficult to tell from such poor material whether or not this is a *Turritella*. If it proves to be *Nerinaea* it may place the age of the rocks in the Cretaceous. However this species is easily recognized by its broad form and may be of use in later correlation.

TURRITELLA NATALENSIS Jenkins, new species.

(Plate XX., Figs. 6 and 6*a*.)

A small, slender shell about 35 mm. long. The longest found was 50 mm. The diameter of the last volution is about 6 or 7 mm.

The angle of the spire is about 12°. The shell has from 16 to 22 volutions, usually 18 or 19, ornamented with two rows of tiny knobs situated at the borders of the volution, close to the suture. The row on the upper side is more prominent and becomes more so the nearer it approaches the top of the spire. In some of the younger or smaller specimens it stands out as a knobby ridge. There is another rather distinct row of knobs or points following the center of the volution. The material is so poor that it is difficult to determine anything further about the ornamentation except that it varies a little among different specimens. Some of the knobs are almost spines, appearing as little points, 6 or 8 on each half volution.

This form is not *Turritella elicita* as given by White, found at Maria Farinha and Ponta de Pedras. It differs principally in the ornamentation, having rows of points instead of ridges on the volutions. Also these rows are not situated in the same positions as in *Turritella elicita,* nor is the angle of the spire nearly so great.

The original shells were never found, so the casts were studied principally from wax molds made from them.

Associated with these fossils were *Cardium soaresanum* Rathbun, some *Cerithiums,* and a *Corbula*-like form. Apparently on top or interbedded with strata containing these were found casts of plant fragments, such as palm leaves.

Numerous casts of these *Turritellas* were found near Itapasaroca, Rio Grande do Norte, in the limestones exposed by the railway cut. In most of the other limestone exposures of this region these same forms occur.

Other Fossil Remains.

(Plate XX., Figs. 3, 5, and 9.)

Other fossil remains were found in the limestones. One appeared to be a portion of a *Pholas*-like shell; another, probably an *Ostrea* (Fig. 3). A larger bivalve, *Cardium*-like, about 25 mm. long and 20 mm. high, was rather common. A small *Cerithium*-like form (Fig. 5) with a sharp, smooth spire, making an angle of 40°, was found and is probably different from the other Cerithiums. A few specimens of a small gastropod (Fig. 9), something like *Natica,*

occurred in some of the beds. A small portion of a segmented animal, probably a crustacean of some kind, is also in this collection. The plant remains are principally impressions of fragments of palms and leaves of other plants. The principal importance of these plants lies in the fact that they indicate estuarine conditions of deposition.

List of Fossils from the Limestones in the Region about Natal, Rio Grande do Norte.

	I.	J.	A.	D.
Pelecypoda:				
Cardium soaresanum Rathbun	*	*	*	*
Cardium (?) larger specimen	*	......	......	......
Corbula (?) sp. ind.	*	......	......	......
Ostrea (?)	*	......	......	......
Pholas (?)	*	......	......	......
Gastropoda:				
Cerithium (?) *mirimense*, n. sp.	*	......	......	......
Cerithium (?) sp. ind.	......	......	......	*
Cerithium (?)	*	......	......	......
Natica (?)	*	......	......	......
Turritella (?) *jacoquea*, n. sp.	......	*	*	......
Turritella natalensis, n. sp.	*	......	......	......
Crustacean (?)	*	......	......	......
Plants:				
Palms, etc.	*	......	......	......

Explanation.—I. is the railroad cut near Itapasaroca; J. is the quarry at Jacoca; A. is the locality near Alvoredo; D. is the outcrop near Desterro.

The Sandstone and Clay Series.

The sandstone and clay series which overlies the limestone is easily recognized by its peculiar character and color. It is a soft quartz sandstone intermixed and interbedded with sandy clay and with small pebbles up to boulders the size of a man's head. Its color is usually a brick red, but varies from white to a dark red-brown; red, blue, yellow, and lavender are some of the commoner shades. These sandstones must carry a large quantity of iron, for its presence is very noticeable at surface exposures. Along the sea-cliffs the leaching and concentrating is marked. It often forms perpendicular bands in the material, alternating hard red columns

to soft white ones, easily washed out by the sea. The harder portions of the concentrated limonitic deposits often form irregular shapes, leaving small holes and caves in which bats sometimes live. These more resisting portions may sometimes be left standing out as mere columns, breaking off before the beating of the waves. When these irregular rough pieces collect together they cement one to another and form a solid rocky point. So well is this cementing process carried on, that it is often hard to find a single loose pebble around a promontory. The soft leached parts of the cliffs are washed away and thrown up on the beach, where the wind carries them back over the country in the form of sand-dunes.

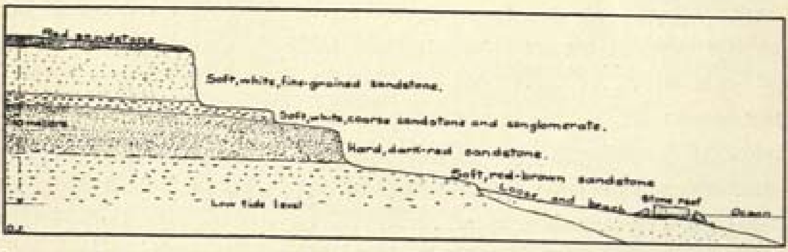


FIG. 10. A typical section of the sandstone series as exposed in a stream cut eight kilometers south of the fort at Natal, Rio Grande do Norte.

All along the coast from Natal to Busios the bed rock which is exposed is that of the sandstone series. The points named on the map and many other smaller ones are all made up of hard red-brown iron-cemented sandstones, which occur in irregular blocks broken down from an adjoining low cliff. In some places, as about eight kilometers south of the Fort at Natal and a hundred meters from the beach, the sandstone series has been cut through by a stream into deep, extremely narrow ravines. The beds are almost horizontal and the general surface is level, but these peculiar cuts break the surface, making it almost impassable although they are not much more than ten meters deep. It is a sort of Grand Canyon type of erosion. In such places bedding may be distinctly observed and the nature of the strata easily studied. The beds vary in texture from a fine soft sand or a clayey sand to a coarse conglomerate. These are interbeded, all carrying more or less clay, and varying in

hardness but usually rather unconsolidated. The amount of iron in the rocks seems to determine their color and also their hardness. These colors vary from white through all sorts of shades, especially red, brown, purple and yellow. Sometimes they are banded or streaked. Sometimes, as at Barreiras do Inferno, certain beds have concentrated all the iron. At this place the undermining action of the waves causes huge iron-sandstone blocks to break off and drop from a ledge three meters thick and these form a pile of irregular shaped boulders along the coast, all cemented together. These cliffs extend for about a kilometer along the coast. Their maximum height is twenty-five meters and they are perpendicular or sometimes overhanging. It is very difficult to pass back of them on account of the deep ravine structure formed there.

Just south of Barreiras do Inferno there are caves formed in the sandstone, which is harder and stands up better than in other places. These caves are formed by the waves at high tide. One cave was noticed which was one meter high, seven meters wide, and ran back five meters into the rock.

Usually the sandstone bluffs are not much over five meters high and the bedding is invisible on account of the peculiar banded perpendicular leaching. This was especially noticed at Morcego and at Pirangý. Here the iron is concentrated in perpendicular bands or columns, leaving a soft sandy or putty-like material in between. Over these bluffs the sand-dunes rest. Probably the rain, which sinks down through the sand-dunes, is regulated in seepage in such a way as to have this peculiar leaching effect on the beds below.

Farther into the country this sandstone series is easily recognized by its peculiar reddish color, visible especially along the low bluffs which border the wide valleys. Also it is seen where the wind-blown sand is only thinly scattered over the surface of the ground.

In all these beds not a single sign of any organic remains was found.

The vegetation on this series is always poor, scanty, and scrubby in form, sometimes almost entirely lacking.

Alluvium.

The only fertile land of the country is the alluvial deposits. They occur in the wide flat valleys as a black, sandy loam containing a good deal of plant matter. These deposits have been carried down by the rivers and washed in by the sea. In some places as in the river by Nåtal, this silting up has not yet been finished. Here mangroves act as a sieve for the sediments. In some places they have only left a comparatively small passage for the water, taking up at least four fifths of the entire valley, which is about six kilometers wide. Their many spreading roots retard the flow of the heavily laden water, which drops its load and thus fills up the channel.

Some marine shells were excavated from an irrigation canal made in the center of the valley of Rio Ceará-Mirim, about ten kilometers northwest of Extremoz and thirteen kilometers from the coast. From their preservation they look as if they were of Quaternary age. They occurred about a meter underground. The valley is very low at this point, said to be two meters above sea level. This shows that the sea must have extended up to this point, probably in a long narrow channel filling the river valley, and since then has been silted out, and possibly the country has been raised.

Borings for wells as far up as Carnahubinha bring up shells of the little rock oyster, *Ostrea equestris,* in great abundance. One well was sunk in the alluvium northwest of Carnahubinha, half a kilometer from Rio Jundiahy and at the depth of twenty-one meters a ledge of these oyster shells was struck. An Indian hammer head was also dug up from a depth of three meters in the alluvium, near the river at Carnahubinha.[4]

This is a deposit of more recent age; in fact the deposition may be observed now.

The most interesting thing about the alluvial material is its extreme depth. It extends below sea level. In fact all the valleys show this sunken condition, for they enter the ocean below sea level.

[4] Information obtained from Mr. John Charles Smith at Carnahubinha, Natal, Rio Grande do Norte.

The *carnahuba* palm is a typical plant of the alluvial deposit. It does not grow in the sandstone series.

This alluvial deposit in the valley occurs farther back into the interior than Macahyba. It could be seen as a wide flat depression many kilometers beyond this point, but its limit was not exactly determined.

List of Quaternary Shells from an Excavation in the Bed of Rio Ceará-Mirim, Ten Kilometers Northwest of Extremoz, Rio Grande do Norte.

Pelecypoda.

†1. *Anamalocardia braziliana* Gmelin.
*2. *Arca (Scapharca) braziliana* Lamarck.
*3. *Arca (Cunearca) deshayesii* Hanley.
‡4. *Arca (Scapharaca) pexata* Say var. *holmesii.*
*5. *Cardium muricatum* L.
‡6. *Chione pectorina* Lamarck.
‡7. *Corbula swiftiana* C. B. Adams.
*8. *Divaricella quadrisulcata* d'Orbigny.
‡9. *Phacoides antillarum* Reeve.
†10. *Phacoides pectinatus* Gmelin.
‡11. *Laevicardium serratum* L.
‡12. *Macoma constricta* Bruguiere.
*13. *Ostrea equestris* Say.
‡14. *Pecten* (near *antillensis*).
*15. *Tellina lineata* Turton.

Gastropoda.

*16. *Anachis lyrata* Sowerby.
*17. *Bulla striata* Bruguiere.
*18. *Cerithium algicola* C. B. Adams.
*19. *Cerithium thomasiae* Sowerby.
*20. *Hemifusus mono* Lamarck.
†21. *Nassa vibex* Say.
*22. *Neritina virginea* Lamarck.

Explanation.

* Shells compared with those collected on the Branner-Agassiz expedition to Brazil and identified by Dr. Dall.[5]

[5] W. H. Dall, "Molluska from the Vicinity of Pernambuco," *Proceedings of the Wash. Acad. Sci.*, Vol. VIII., pp. 139–147. April 15, 1901.

† Shells compared with those from collections from Florida. These are also listed in this same paper of Dr. Dall's.

‡ Shells identified by Dr. Dall, November 21, 1912, who says:

"These shells are (except *Pecten*) identical with West Indian forms

now living, most of which also live on the Brazilian coast. The *Pecten* may also be, but we don't happen to have it."

All the rest of the shells are West Indian forms now living. The age of the deposit is probably late Quaternary. The deposit is evidently estuarine, the sea having extended into the old river channel in a narrow embayment. The water was mostly salt, but partly brackish, for *Bulla, Cerithium, Neritina, Corbula, Ostrea,* and possibly *Arca* (making a total of nine species out of twenty-two) are brackish water forms. *Neritina virginea* is sometimes found even in practically fresh water.

Log of a Well at Natal, Rio Grande do Norte.

(Reported by R. H. Soper in a letter of Sept. 21–29, 1912, to J. C. Branner.)

"I give here the log of a well which was drilled about one mile [two kilometers] from the bridge, toward Natal, across the river from Natal, and on the low marshy ground which borders the stream. The figures are from Burgess, the driller whom you may remember as the German who drilled the well in the crystalline stuff at Baixa Verde. He kept samples systematically which I saw and from which I compiled this record.

Meters.	
0–32	All a blackish, sandy, sticky, clayey mud. All contains more or less water which is salty.
32–41	A sandy clay, mixed with pebbles and boulders of quartzite. The largest pebble in the sample was about the size of a hen's egg.
41–42	White fine-grained sandstone.
42–44	Yellowish brown, clayey sandstone.
44–46	Whitish clayey sandstone.
46–50	Fine-grained reddish sandstone with occasional large pebbles of quartzite.
50–55	Dark, fine-grained sandstone with some clay and a little mica.
55–57	Quartzite pebbles with chunks of a mineral which gives a sharp biting taste like sal ammoniac.
57–64	Dark colored fine-grained sandstone which gives place to a hard, coarse-grained sandstone.
64–67	Dark pebbles of quartzite with pieces of hard, coarse-grained, vitrified sandstone.
67–82	A very fine-grained sandstone with considerable clay. Very hard. Comes out wet and black. Is a grayish white when dry.
82–87	A hard, brownish, sandy clay. When wet it was very black and could only be removed from hands with kerosene. Had a bad smell.
87–88	Same as 67–82.
88–94	Same as 82–87.

94–103 Coarse, grayish, clayey sand.
103–107 A brownish and grayish fine-grained, sandy clay which is black when wet.

"I might add that the well stopped here. There was more or less water all the way down but none of a drinkable quality. The name of the place where this well is located is 'Porto do Padre.' Burgess told me that when the tide was high, the level of the water in the well was low and when the tide was down low, the level of the water in the well was up."

The Sand-Dunes.

The action of the sand-dunes on the northwest coast of Brazil is of great importance. It is best studied along the coast for there the waves sometimes cut into the banks and expose dunes of older ages. Cross-bedding is the general form which it takes, distinctly marked, and overlying the soft red sandstone series. The sand is composed almost entirely of white quartz grains. It is blown back from the coast and across the country. It forms long parallel hills of yellowish color across the railroad south of Natal just north of Pitimbú. Here it has been carried from Ponta Negra. This form is common all along the coast in a belt about ten kilometers wide.

An interesting work of the wind and sand was that in the valley Extremoz. At the mouth of the valley, which is about two kilometers wide, there is a bank of sand-dunes some thirty meters in height, completely shutting in the basin. This bank must have existed some time, for a small lake, bordered by cocoa-palms, is nestled in its crest. The valley back of it contains a series of long, narrow freshwater lakes more or less connected end to end, but distinctly separated on their sides by long parallel dunes running lengthwise up the valley, standing almost as high as the surround-

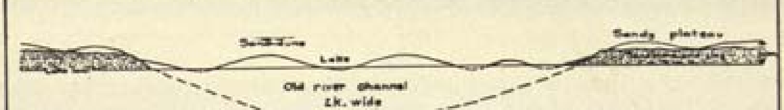


FIG. 11. Cross-section of the Valley of Extremoz, Rio Grande do Norte, showing the system of parallel lakes between the sand-dunes which dam it up.

ing low plateau. These dunes are of old character, dirty, and covered with vegetation. In some places the lakes are round, but usually they are long and narrow. They are bordered by little or no vegetation. Nearby a cocoa-palm grove may stand with its tiny village. This condition continues for ten kilometers up the valley to Logoa Agramara. Beyond there are a few meadows, dried-up ponds, and sand-dunes which close up the valley farther on. Logoa Extremoz is a horseshoe shaped body of water beyond the sand-dunes, situated at the junction of the two old river beds which go to form the main valley. This lake has a tiny outlet which runs into a marsh where it is dried up and sinks into the sand. The village of Extremoz lies on its northern shore and the railroad passes in sight of it. The general appearance of the lake as viewed from the car window was that of a river, not a lake. Further examination showed it to be a lake in an old river channel with two inlets, one at each of the ends of the horseshoe. "The fish fauna of Lake Extremoz is made up of the usual fresh water forms of the region and, in addition, many typical salt water ones, such as *Centropomus, Mugil* and *Gerras,* showing that the lake has been connected with the sea in recent years, though it is said to be cut off by sand hills at the present time."[6] These marine fishes are known to live for years in the fresh water of the tropics but are not known to spawn there. The habit of spawning in sea water is too great to be readily changed. At Ceará-Mirim only fresh water forms were found. At Paparý both fresh and salt water forms were found in the lake. The lake in this case, although dammed at the mouth by sand, has at present a direct connection with the sea. It is hard to see, in the case of Logoa Extremoz, how fish can ever get out or how they have existed, being away from the sea apparently for so many years. It is evident that at times of great floods the lake must connect with the ocean.

This damming in of fresh water is a common occurrence along the coast but not always on such a large scale. Paparý, which is farther down the coast, is a river basin partly dammed in by dunes at its mouth and made into a lake.

[6] E. C. Starks, "The Fishes of the Stanford Expedition to Brazil," p. 3. Stanford University, March 17, 1913.

The gaining of the dunes over the river is most probably done in times of drought, for then they can fill the river, cross it, and be carried into the valley.

Economic Geology.

Building Stone.

The crystalline series of rocks contains good building stones, such as granites. Far into the interior there are marbles, but they are rather inaccessible now. Granite is now quarried at Macahyba by the method of cooling the rocks suddenly by throwing water on them after they have been heated by fire. On account of the scarcity of large timber and its rapid decomposition due to climatic conditions and the work of such insects as ants, building stone is an important factor. The ordinary houses are usually made of mud with a reënforcement of slender limbs of shrubs and trees.

Lime.

The limestone series affords a means of making lime and cement. It is quarried where it is found exposed at the surface, but could be obtained at many other places if sought for. The quarries contain bedded rocks of varying economic value. Some of the beds are mostly siliceous, while others are almost entirely composed of calcium carbonate. Three specimens were dissolved in weak hydrochloric acid and gave the following percentage of insoluble matter, varying from 4 per cent to over 20 per cent.

Locality.	Percentage of Insoluble Matter.
Jacoca	10.5
Masaranduba	3.9
Itapasaroca	20.1

The limestone belt, occurring next to the granitic series, affords a means for obtaining cement to use in the same place in connection with the building stone.

Clay.

The clay in the upper sandstone series is sometimes quite pure. It is the material of which the native huts are made. In some places

the purest clay is used for making pottery and bricks. Ornaments, household utensils, such as vessels for holding water, are made at Santo Antonio and at Barreiros. These vessels are red-brown in color and rather easily broken. They appear to have been patterned after Indian styles, which may be a result of the Indian blood in some of the people of this region.

Soils and Agriculture.

The distribution of plants in this region is very striking; they are dependent upon both soils and climate. Thus the rubber tree and other shrubs grow over the sandy plateau region. Farther into the interior the region is arid, almost a desert. Here the soil is of decomposed granites and other crystalline rocks, and cacti and desert shrubs are the principal plants.

Bordering the great valleys, in the old alluvial flats, the *carnahuba* palm is the prominent tree, although this region produces many other plants more or less intergrown. Occasionally forests of trees as high as twenty meters may be found in these old filled-in valleys, as the forest between Monte Alegra and Desterro.

The mangrove swamps are typical of the borders of the estuaries and streams. Here deep black mud is deposited. This alluvium is what makes the fertile soil.

Along the beach one might suppose that there was no vegetation, but on the shores of almost every little cove there is a grove of cocoanut palms and a little fishing village.

The valleys contain a great deal of sand, but are on the whole fertile. The natives use the most primitive methods in farming. There was not a single plow seen about Natal. The soil contains enough sand to keep itself fairly loose and the plants are simply stuck in the ground and left there. Bananas, sugar-cane, cotton, corn, and various kinds of tropical fruits are raised. Occasionally coffee bushes are grown in the shade of other trees. Mandioca is raised in great abundance. Its root is made into farinha, the principal food of the common people.

At Carnahubinha there is a cotton-seed oil factory. Also at this place salt is concentrated from the sea water which flows up the Jundiahy at high tide.

Water-Supply.

The abundant rains along the coast sink into the sand immediately, but on coming in contact with the clayey beds of the sandstone series below, they are not able to pass farther down, so they emerge at low places. These low places are often between sand-dunes. Thus along the sea-coast, natives draw water from holes dug in the sand and the water is soft and fresh.

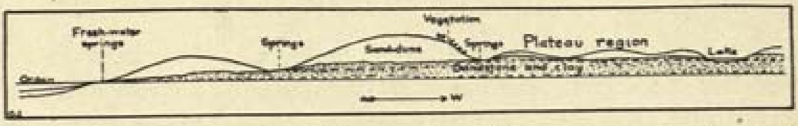


Fig. 12. General section of the coastal sand-dunes, showing how the fresh-water springs occur. Rain sinks through the sand-dunes and emerges where impervious beds of the clayey sandstones are exposed.

On the opposite side of the river from Carnahubinha there is a place called *Agua Doce*. Here excellent drinking water is obtained. The sand-dunes form an amphitheater around one side of the small depression, which is about fifty meters across. The water is bubbling up all the time and carries away the sand as fast as it is blown into it. Fresh water occurs in a certain point in the river near this place, although the river carries salt water from the sea. Here it is said that a hole twenty-two meters deep is present, while the rest of the stream has only the depth of six meters.[7] Similar holes usually occur near the bank where a sand-dune is present.

This form of spring supplies the small lakes of the plateau region with water the year around, as in the region north of Paparý. Here, along the border of some of the lakes, such as Logoa Bom Fim, such springs were found feeding the lake directly.

The rivers carry the water down from the interior. Often they are dammed at their mouths and form lakes. These lakes are valuable to the people, whose villages are clustered about their shores, as at Paparý.

Farther into the interior the lack of water is a serious matter. Sometimes great droughts drive the inhabitants from the country.

[7] Information obtained from Mr. J. D. Smith at Carnahubinha.

The occurrence of granitic rocks does not afford the means of obtaining underground water as in the region of the sedimentaries along the coast.

Effects of Climate, Etc.

All the ocean currents and the winds constantly sweep up the coast towards the northwest. The water is warm and the atmosphere balmy. The greatest rains and the hottest weather occur during the months of our winter. During our summer the rains are more scarce and the atmosphere cooler and drier. The region about Natal does not have such heavy rains as some of the other parts of Brazil such as those nearer the equator. In fact the country about Natal is very healthful.

The direction of the winds and the ocean currents affects the coast line in that all the bars, spits, reefs, and promontories tend to point up the coast to the northwest.

The stone reef at Natal affords the maintenance of a quiet harbor.

Effect of a Sunken Coast.

A sunken coast affords fine harbors. Cities occur at the points where arms of the sea extend up the river channels. Natal is a good example of such a city beside a harbor thus formed. The tides which flow up and down these channels give to the people an easy method of transportation.

Effect of Silting.

A constant annoyance to the people is the perpetual silting up of the channels and the shifting of sands and the formation of sand bars in their harbors. These things change rapidly, being dependent largely on the amount of rainfall, the flow of the rivers, and the intensity and direction of local currents.

Mangroves help the silting process to a great degree, but still these swamps when drained finally make up the fertile lands of the country.

The depth of the silt in the river channels often causes disturbance to the people when they attempt to drive piles in the mud and cannot find bed rock.

Summary.

There are three principal series of rocks in the region about Natal: the particolored sandstones and clays, exposed as sea-cliffs; the underlying fossiliferous beds of limestone; and the crystalline rocks in which are schists, gneisses, quartzites, shales, granites, etc. The sedimentaries form a belt along the coast about thirty kilometers wide, while the crystalline rocks make up the interior country. Besides these formations the alluvial deposits in the valleys and the wind blown sands of the coast are important features of the geology of this region.

The most important results from this work are as follows:

1. The determination of an unconformity between the particolored sandstone and clay series and the underlying limestones.

2. The finding of fossils in the limestones.

3. The determination that the limestones were laid down as estuarine deposits, thus indicating a sunken coast at that time such as exists now.

4. The proof that the coast has sunken recently, and the commercial effect that this condition has had upon the country in affording fine harbors, and in making good agricultural land by the deposition of silt in the rivers forming fertile valleys.

5. The effect wind blown sand has upon the country in damming streams and thus forming fresh-water lakes.

6. The large supply of good water in the region of the sedimentaries in comparison to the lack of water in the dry interior.

Leland Stanford University,
California.

EXPLANATION OF PLATE XX.

FIG. 1. *Corbula* (?) sp. ind. Drawing from a wax mold.

FIG. 2. *Cardium soaresanum* Rathbun. Composite drawing from several wax molds.

FIG. 2*a*. *Cardium soaresanum* Rathbun. Showing inside cast of shell.

FIG. 3. *Ostrea* (?). Drawing of an impression of the shell.

FIG. 4. *Cerithium* (?) sp. ind. Drawing from a wax mold.

FIG. 5. *Cerithium* (?). Drawing from a wax mold.

FIG. 6. *Turritella natalensis* n. sp. Composite drawing from several wax molds.

FIG. 6*a*. *Turritella natalensis* n. sp. Showing inside cast of shell.

FIG. 7. *Turritella* (?) *jacoquea* n. sp. Composite drawing from several wax molds.

FIG. 7*a*. *Turritella* (?) *jacoquea* n. sp. Showing inside cast of shell.

FIG. 8. *Cerithium* (?) *mirimense* n. sp. Composite drawing from several wax molds.

FIG. 8*a*. *Cerithium* (?) *mirimense* n. sp. Showing inside cast of shell.

FIG. 9. *Natica* (?). Outline of the impression of the shell.

SANDSTONE REEF AT NATAL, RIO GRANDE DO NORTE.

FIG. A. Looking from the old fort along the reef, showing the stranded steamer on the reef at the far side of the bar.

FIG. B. Looking northeast along the coast from Asylo de Mendicidade, showing the same stone reef.

Photographs by G. A. Waring, 1912.

RIO GRANDE DO NORTE REEFS.

FIGS. A AND B. Looking north along an organic reef off the coast from Piringy. Photographs by E. Leib, May, 1911.

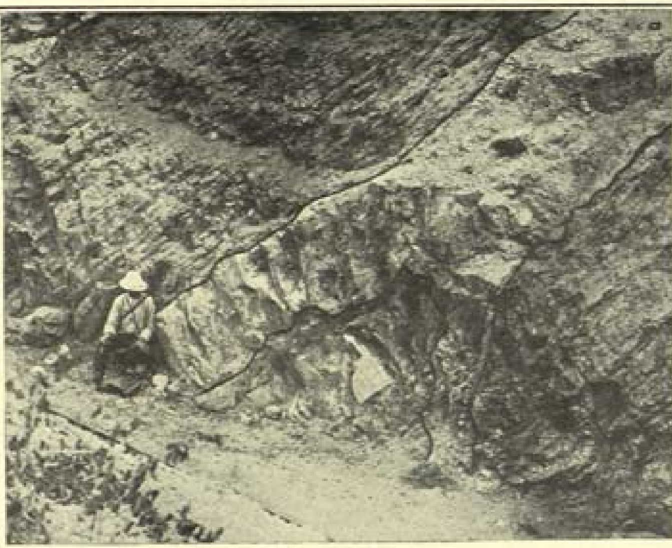
FIG. C. Looking along the sandstone reef at Natal toward the fort, showing etched and fallen blocks. Photograph by G. A. Waring, Nov., 1911.

CRYSTALLINE ROCKS EXPOSED IN RAILWAY CUTS NEAR BAIXA VERDE, RIO GRANDE DO NORTE.

FIG. A. Showing weathering of the dike rocks in the third cut northwest of Baixa Verde.

FIGS. B AND C. Granite-pegmatite dikes in biotite-schists, second cut beyond Baixa Verde. Fig. c shows the levelling of the surface by decomposition. Topography is not affected by these dikes and schists.

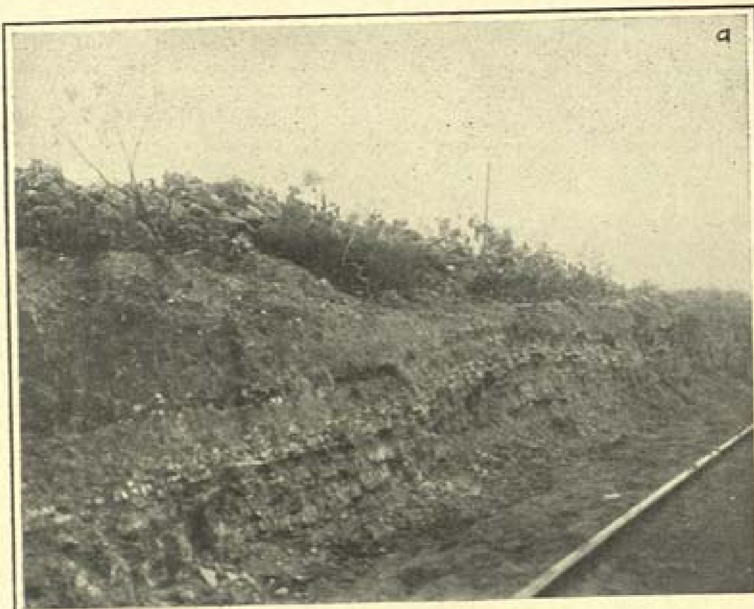
Photographs by E. Leib, May, 1911.



CRYSTALLINE ROCKS OF THE INTERIOR, RIO GRANDE DO NORTE.

FIG. A. Y-shaped pegmatite dike in biotite-schists near Baixa Verde. Photograph by E. C. Starks, May, 1911.

FIG. B. Granitic serrotes on the gneissic plain, Rio Grande do Norte. Photographs by G. A. Waring, 1911.

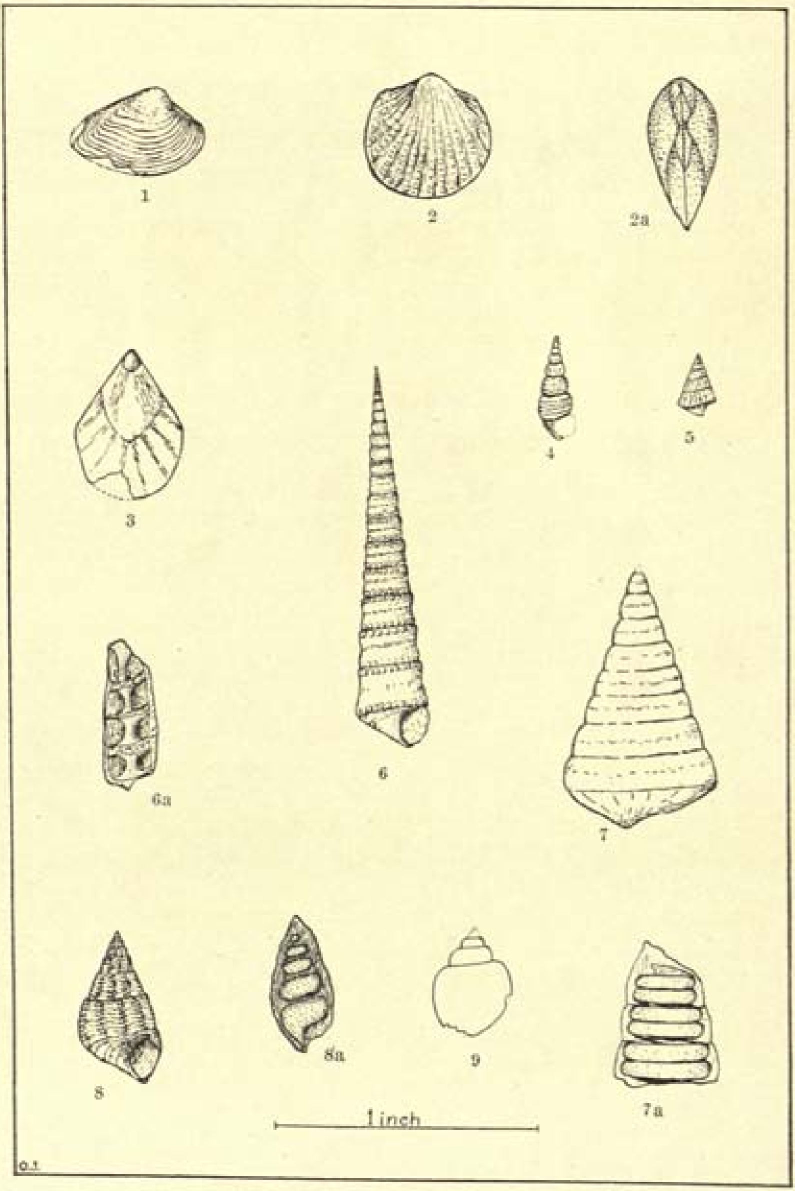


FOSSILIFEROUS LIMESTONES ONE KILOMETER WEST OF ITAPASAROCA, RIO GRANDE DO NORTE.

FIG. A. Looking east. The beds dip eastward about 5° into the plain.

FIG. B. Looking west. The beds are thrown into waves here.

Photographs by E. C. Starks, May, 1911.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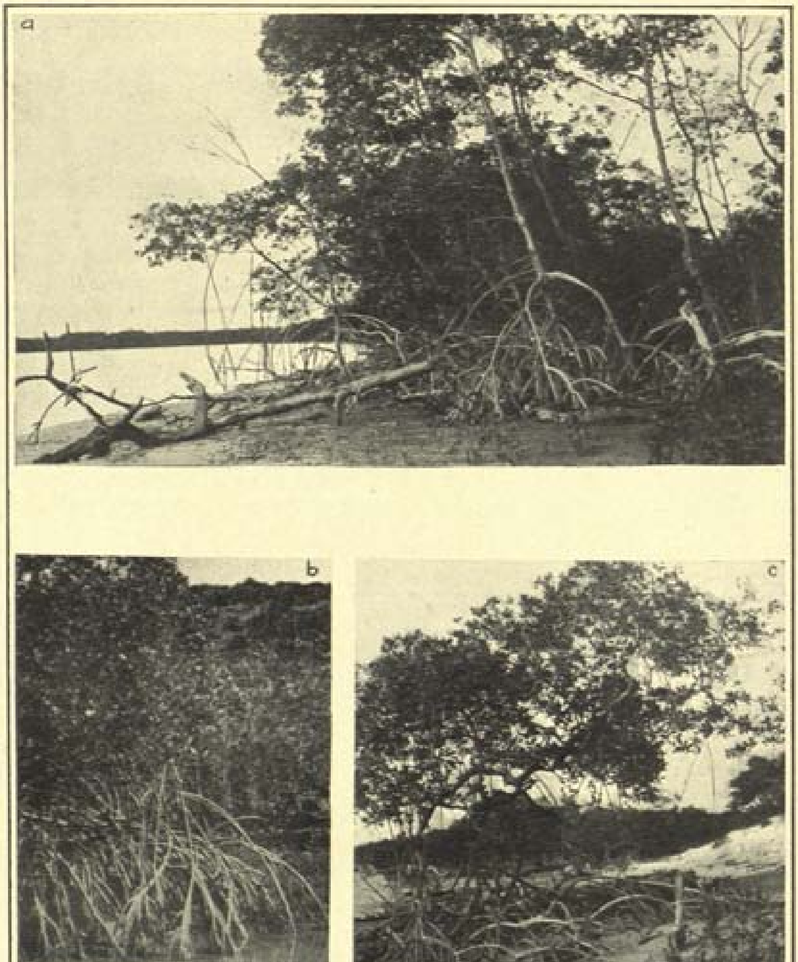
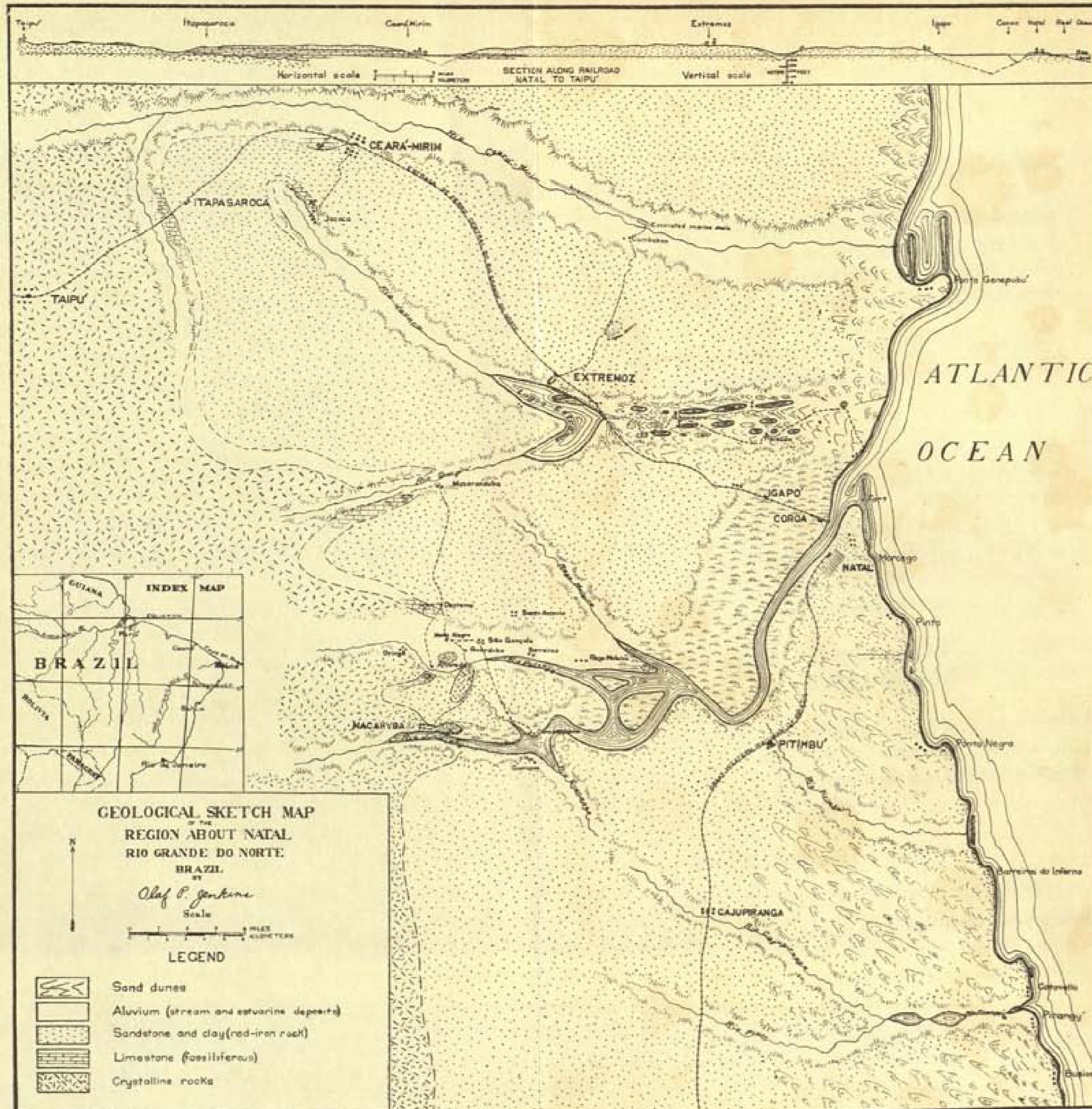


Mangrove Roots, Silting of River Mouths.

Figs. a and c. Mangrove roots at low tide, Tutoya, Maranhão. Photographs by G. A. Waring, 1911.

Fig. b. Mangrove roots at the mouth of Rio Pirangý, Rio Grande do Norte. Photograph by E. Leib, 1911.


Taipu'
Itapasaroca
Ceará-Mirim
Extremoz
Igapo
Natal
Horizontal scale
SECTION ALONG RAILROAD NATAL TO TAIPU'
Vertical scale
CEARÁ-MIRIM
ITAPASAROCA
TAIPU'
EXTREMOZ
ATLANTIC
OCEAN
Ponta Genepubu'
IGAPO'
COROA
NATAL
Morcego
Pinto
MACAHYBA
PITIMBU'
Ponta Negra
CAJUPIRANGA
Barreiras do Inferno
Pirangy
Búzios
INDEX MAP
GUIANA
BRAZIL
BOLIVIA
Rio de Janeiro
GEOLOGICAL SKETCH MAP
OF THE
REGION ABOUT NATAL
RIO GRANDE DO NORTE
BRAZIL
BY
Olaf P. Jenkins
Scale
MILES
KILOMETERS
N
LEGEND
Sand dunes
Aluvium (stream and estuarine deposits)
Sandstone and clay (red-iron rock)
Limestone (fossiliferous)
Crystalline rocks

GUATEMALA AND THE HIGHEST NATIVE AMERICAN CIVILIZATION.

By ELLSWORTH HUNTINGTON.

(*Read April 18, 1913.*)

By common consent the most backward part of our continent is Central America. Among the republics of Central America Guatemala is considered to hold the lowest place. In Guatemala it is universally agreed that the province of Peten is the wildest, most uncivilized and most uninhabitable part. Peten, then, may be regarded as at the very bottom in the scale of American civilization. Its native inhabitants are either absolute savages, or semi-barbarians, densely ignorant and highly inefficient. Nevertheless in the past this region was the home of the highest civilization that ever developed in any part of the western hemisphere, a civilization which was not transitory, but lasted hundreds of years. It seems to have grown up where we find its traces, since nowhere else do we discover any premonitions of it. Here the ancient Mayas developed a unique system of architecture, whose earlier stages appear at Copan and the ruins of Peten, while its latest and most showy, although decadent, expression is found in the wonderful ruins of Yucatan a few hundred miles farther north. In this same part of Guatemala the Mayas devoloped the art of sculpture to such a point that their statues, though crude in many ways, represent the features of the ancient populace so exactly that type after type among the modern population is easily recognized in the monuments. Here the Mayas attained such skill in the mechanic arts that great stones fifteen to thirty feet long, and weighing 20 to 80 tons were transported from quarries a mile or two away and set up in the midst of great court-yards or temple areas. The buildings themselves were elaborately planned and decorated with all manner of carefully carved designs. All this was done with no tools, so far as can be

ascertained, except obsidian or flint. A greater achievement than this, however, was the construction of a calendar much more accurate than any known even in Europe until the introduction of the Gregorian calendar which we now employ. The construction of such a calendar must have demanded carefully written records for hundreds of years. This brings us to the greatest of the achievements of the Mayas. They had developed the art of writing in hieroglyphics, and apparently their type of hieroglyphics was higher than that of the Egyptians, for they seem to have been on the point of using specific symbols not to represent words but sounds, a step which even the Chinese have not yet taken.

From the point of view of the geographer, and perhaps of the historian also, the most remarkable feature of the civilization of the Mayas is that it developed in almost the worst physical environment to be found in any part of America. It might have developed in the healthful plateau of Guatemala where cultivation of the soil is easy, and where the population to-day is dense and relatively efficient, but instead of this it developed a hundred miles away in the fever stricken lowlands of Peten, where agriculture is extremely difficult and the population almost negligible. To-day for some unexplained reason the distribution of population and still more of culture in Guatemala is utterly different from what it was in the past. Perhaps nowhere else in the whole world have less than 2,000 years produced so profound a change, not only in the state of civilization as compared with other parts of the continent, but in the relative importance of different portions of the same small country no larger than the state of New York. The normal decay of races, the interplay of historic forces, the invasion of barbarians, the decadence due to luxury, vice and irreligion, the change of the center of world-power, or some of the other causes usually appealed to by historians may explain why the Maya civilization arose and why it fell. We may assume that it arose because it is the nature of a young and vigorous race to make progress, and that it fell because it is the nature of an old and exhausted civilization to decay. This, however, does not touch upon the problem which we propose to discuss in this paper. To-day the most progressive and energetic

people of Guatemala, its densest population, its greatest towns, its center of wealth, learning and culture, so far as these things exist, are all located in the relatively open, healthful, easily accessible and easily tillable highlands; in the past these same things were located in the most inaccessible, unhealthful, and untillable lowlands. Why the change?

Before we attempt to answer this question, it will he helpful to discuss the geographical provinces of Guatemala as they exist to-day, and as they were seen by the author during a recent visit, and to compare them with one another. From the point of view of present habitability Guatemala together with British Honduras, which is physically part of the same country, may be divided into three main belts dependent on vegetation,—(1) the Atlantic forest, (2) the central dry land, and (3) the Pacific forest. Each of these in turn may be divided into two parts. The plain of British Honduras in the north to a width of fifty miles, and the mountains of the southern part of that country and of eastern Guatemala to a distance of perhaps thirty miles from the coast form the first division of the Atlantic forest. Showers at all seasons either from the trade winds in our winter, or from the subequatorial area of low pressure in summer cause the land to be covered with a dense tropical forest, and to be infested with malignant types of malarial fevers. Only on the coast are there any real towns, and they exist chiefly by grace of the trade winds, which blow freshly from the ocean and drive away the mosquitoes. Strung along the beach under the cocoanut palms the low whitewashed houses of these towns make quite a show from the sea, but back of the first row there is often nothing but deadly swamp and mosquitoes. In the interior a few little villages sit in clearings by the brink of the somber rivers, and wait in sun or rain for precious mahogany logs to be hauled or floated out of the interior. Save for this, almost no one except an occasional gatherer of gum inhabits the dense forests. If the coast towns and the mahogany cutters be excluded the whole region cannot boast a population of much more than one person to every ten square miles, while even if the towns and woodcutters be included, British Honduras with an area of 7,500 square miles has only

42,000 people, or less than 6 to the square mile. The forests and fevers now keep mankind away, and apparently much the same was true in the past, for we find here only a few widely scattered ruins.

Inland from the coast strip there lies another section of the Atlantic forest, occupying most of the almost unexplored and semi-independent Guatemalan province of Peten, and extending south past the ruins of Quirigua towards those of Copan. In the north this Peten strip consists of a plain from which rise a few low ridges running east and west, and having a height of a thousand feet more or less. In the south it becomes mountainous. The vegetation is almost as dense as that of the coast strip except that in Peten considerable areas of grassy savanna prevail, thin pine forests grow in the sandy tracts known as "pine ridges," and on the westward edge and in other favored spots, among which Flores on L. Peten is the chief, the forest breaks down into jungle. The savannas appear to be due either to an excess of water often held near the surface by clayey hardpan, or to sand. The pine ridges, which are not ridges but merely slight swellings in the plain, are due to accumulations of sand. Neither in the past nor at present does it ever appear to have been possible to cultivate either the savanna or the pine ridges, but since the introduction of cattle by the Spaniards they have been utilized somewhat for pasturage. They possess not only the advantage of being fit for cattle-raising, but of being relatively healthful, and of being bordered by narrow strips of jungle wherein primitive agriculture is possible. The jungle regions on the immediate borders of the Peten strip, contain a few villages, among which Copan is most worthy of mention. Aside from the limited areas of savannas, pine ridges, and jungle, the country is covered with forest, and is so feverish and so difficult to cultivate that its only inhabitants are mahogany cutters, gatherers of chicli gum, or raisers of bananas for export. All of these occupations, together with cattle-raising, are due entirely to the influence of modern European civilization, and had no place in the pre-Columbian period. The banana plantations have grown up within a few years and are practically all the work of the United Fruit Company, which employs four or five thousand people in the valley of the Motagua river.

Only some powerful stimulus, like the demand of the United States for fruit, could cause such plantations to arise. The strictest supervision is necessary in order that the bushes may be cut every three months, for in a year the native vegetation grows ten feet or so, and if left to itself would soon choke the banana plants. Still more unremitting vigilance is necessary to keep both the white men and the natives in health. From the wages of every employee, whether he receive fifty cents or fifty dollars per day, the Company takes two per cent. to pay for sanitary measures. Every plantation has its doctor and dispensary, and natives and foreigners are continually dosed with quinine. Yet even so, at certain seasons of the year, a single train may carry a score of staggering fever patients, the present hospitals are wholly inadequate, and in 1913 the company was erecting a new hospital at a cost of $125,000. Mr. Victor M. Cutter, manager of the Guatemala division of the United Fruit Company, states that about ninety per cent. of the people in his district, both natives and whites, suffer from malaria and its sequelæ. In spite of all precautions about twenty per cent. have the fever in a serious form.

In the entire Peten strip of the Atlantic forest, from Copan on the south up through Quirigua, the lake of Izobal and the province of Peten, it is probable that the total population does not exceed 20,000 in an area of nearly 15,000 square miles. If the cattle-raisers, mahogany cutters, gum gatherers, and banana raisers be excluded, and if we include only the people who procure a living in ways possible before the coming of the white man, the population is reduced to probably less than ten per cent. of the figures given, or only one person for seven square miles. Of course these figures are a mere approximation; there is no such thing as a census, for much of the country is still unexplored, and the wild Indian tribes practically ignore the Guatemalan supremacy. For day after day, however, the traveler finds no inhabitants, and place after place which appears on the map as a village proves to have only two or three houses or to be merely an abandoned hut. Roads and even trails are almost non-existent, and in most places the machete must constantly be used to open up a pathway. Mr. Frank Blanceneaux,

who for six or seven years spent a large part of his time in traveling through Peten in search of mahogany, probably knows that province as thoroughly as any one. He thinks that the population does not exceed 10,000, and that at least 95 per cent. of it consists of cattle raisers, mahogany cutters and gum gatherers. Nowhere has he seen a village of more than a hut or two in the genuine forest, and nowhere do people practice any real agriculture in the forest as opposed to the jungle. South of Peten, along the line of the railroad from Puerto Barrios to Guatemala, for sixty miles from the Atlantic coast until one comes to the poor little village of Los Amates, there would not be a single inhabited place were it not for the railway itself and the banana plantations of the United Fruit Company. Los Amates lies on the edge of the forest where it breaks down into big jungle.

Whatever may be the exact figures as to population it is evident that heavy rains, dense vegetation, and malignant fevers to-day render the Peten strip of the Atlantic forest almost uninhabitable. Yet in the past this was by no means the case. Practically all of the great Maya ruins outside of Yucatan lie in this strip or in its northern and northwestern continuation in the Mexican provinces of Chiapas, Tabasco and Campeche. Copan, one of the most remarkable of the ancient cities, lies on its edge, although not actually in it; Quirigua lies within it, although only a few miles from the border; and Seibal, Tikal, and a score of others as far as Palenque in the north, lie well within its dense jungle and forests. These places were obviously towns of importance, such as grow up in interior, agricultural districts far from important lines of communication only when there is a considerable population round about. How dense the former population may have been we cannot estimate, for the cover of vegetation is so thick that we have no idea of the exact number of ruins. It is scarcely an exaggeration, however, to say that for every family now supported by ordinary agriculture, there was probably a village or hamlet, in the days of the Mayas, and for every modern village a city.

Turning now to the relatively dry portion of Guatemala, the second of our three divisions, we find it divided into arid bush

country, lying in low, isolated valleys or basins such as Zacapa, and highlands where pine or temperate forests prevail. The bush country is unimportant, being of small area. In some places it is so hot and dry that cacti and mesquite bushes make it look like the lowlands of Arizona. It is fairly well inhabited and moderately healthful. The people are in advance of the poor denizens of the forest zone but are miserably inefficient, idle, weak-willed, and immoral. The real strength of Guatemala is in the highlands, where the vegetation takes on an aspect suggestive of the temperate zone. There, on the plateau amid pine-clad hills at an altitude of 4,000 to 8,000 feet, all the large towns are now located. The conditions of health, from a tropical point of view, are everywhere good. Typhus, dysentery and other disorders, to be sure, often sweep the country; and faces pitted by smallpox are frequently seen. These diseases, however, although causing a high death rate, are temporary. Their ravages are as nothing compared with those of the deadly malarial fevers which in the lowland forests return season after season to blight and destroy the same places and the same people. From the coast upward, according to universal testimony, the health, energy, industry, and thrift of the native Guatemalans in general show an increase. It seems a curious reversal of what we are wont to call normal conditions, when one sees rich, fertile plains along the coast almost uninhabited, then finds the population fairly dense on steeply sloping, stony mountain sides at altitudes of three to five thousand feet, and finally on the hilly plateau at 8,000 feet sees little thatched houses clustering thickly everywhere, and every available bit of land almost as carefully and industriously cultivated as in China. Even more curious, perhaps, is the fact that here where the population is now so dense there are relatively few important ruins and none of the advanced type found in Peten. There is no reason to think that ruins which once existed have disappeared to any greater extent than has happened in Egypt, Syria, Greece, Rome, or any other country where a high civilization in the past has been followed by a dense population at present. Moreover ruins of a certain kind are found in considerable numbers, but they are insignificant and probably of late date compared with those of Peten. The carved

stones which one sees, for example, at Guarda Viejo near Guatemala City are small, crudely executed, and inartistic, utterly different from the clean-cut, highly complex and truly artistic stelæ of enormous size at Quirigua. The plain, almost unadorned structures at Quiché, the greatest ruins on the plateau, bear to the highly developed groups of buildings and monuments at Copan about the same relation that modern Guatemalan churches bear to St. Peter's at Rome. In the days of the Mayas the highlands may have been as densely populated as to-day, although we have no positive proof of this, but instead of being the center of the life and activity of the country they were a provincial outpost.

The southwestern side of the high plateau of Guatemala is bordered by a line of splendid volcanoes at the foot of which towards the Pacific Ocean there lies a narrow plain. This plain, together with the lower slopes of the mountains, forms the third of our three divisions of Guatemala from the point of view of habitability. From a height of 4,000 feet down to about 500 the slopes of the mountains and the inner edge of the plain are covered with dense vegetation. At an altitude of approximately 2,000 to 3,000 feet, the vegetation attains the dignity of real tropical forest with mahogany trees, tree ferns and the like, while on either side it assumes the form of forest-like jungle merging gradually into pine forest toward the uplands and low jungle and bush toward the coast. All except the upper mountainous part of the region is malarial and unhealthful; although not so bad as the Atlantic forest because the drainage is better. The strip of real forest would to-day be practically uninhabited were it not that the demands of the modern civilized world have led to the cultivation of coffee, chiefly by German companies with Indian labor brought from the highlands. Lower down, on the edge of the plain, there would be a small population even without the impetus of coffee. A few little towns like Retalhuleu, Santa Lucia, and Escuintla date back many centuries. They are notoriously unhealthful, however; their inhabitants are universally pronounced inefficient and apathetic; and their population of from 2,000 to 10,000 people is only 10–20 per cent. as large as that of corresponding towns on the plateau. Yet, here, curiously enough, we

again find abundant traces of an ancient race of relatively high culture. The ruins are by no means equal to those of the Peten strip, and there appear to be few hieroglyphics. Nevertheless they belong to the same civilization although to a later stage subject to foreign, that is Nahua, influence. At places like Baul and Pantaleon great blocks of hard basalt have been found carved with scenes of sacrifice, or chiseled to represent gigantic faces whose peculiar types of slit nostril, high cheek, or projecting mouth can still be recognized in individual Indians.

The seaward portion of the Pacific belt needs little further comment. Beginning with jungle where the modern towns and ancient ruins come to an end, its shoreward portion is covered with dense, low bushes among which short bamboos are often conspicuous. Although dry and parched in the winter season, much of it becomes a vast swamp when the rains swell the mountain streams and cause them to spread out over its flat expanses. Mosquitoes then abound causing fevers which are often of the "pernicious" type accompanied by hemorrhages of blood producing immediate death. Practically the only inhabitants are a few cattle raisers, who are described as the lowest of the low. In the past, conditions were apparently no better, for we find no trace of ruins here.

Before we consider the possible causes of the contrast between the past and present, it will perhaps add to the clarity of our ideas if our six belts are arranged in tabular form.

It is worth while to emphasize the strange contrast between past and present. The belts immediately along the Atlantic and Pacific coasts may be left out of account, since in the past, just as at present, they appear to have been too forested and too feverish for human occupation to any great extent. To-day the other four divisions stand in the following order so far as progress, achievement, and density of population are concerned; first the highlands, second the dry valleys, third the coffee belt, fourth the Peten strip. In the past the ruins tell a very different tale,—the Peten strip stood first, then the coffee belt and the dry valleys, and last of all the highlands, the reverse of the present order. To-day, in Central America, the physical conditions under which mankind tends most to increase in

	Nature of Vegetation.	Health Conditions.	Condition of Agriculture.	Present Density of Pop.	Condition of Population.	Abundance and Condition of Ruins.
1. Atlantic coast	Dense forest	Very unhealthful	Very difficult	Very scanty	Degraded	Very few so far as known but of fairly high type
2. Peten belt	Dense forest with some savannas and jungle	Very unhealthful	Very difficult	Very scanty	Degraded	Numerous and indicating the highest native American culture
3. Dry valleys	Bush or low jungle	Fairly healthful	Fairly easy	Moderately dense	Low, but well ahead of 1, 2, and 6	Moderately numerous and of fairly high type
4. Highlands	Pine forest	Healthful	Easy	Very dense	By far the best in Guatemala	Quite numerous, but mostly of rather low type, that is, provincial or degenerate
5. Pacific coffee belt	Forest and jungle	Unhealthful	Fairly difficult	Rather scanty	Low, but ahead of 1, 2, and 6	Moderately numerous and of fairly high type
6. Pacific coast	Bush	Very unhealthful	Difficult	Very scanty	Degraded	None so far as known

numbers and to progress in culture appear to be high altitude, good drainage, and a fairly long, dry season. Altitude in itself, however, does not appear to be essential, for the low dry plain of northern Yucatan seems as well off as the highlands of Guatemala. Perhaps the exposure of that part of Yucatan to the ocean and to strong winds from the north produces the same effect as elevation. Opposed to these favorable conditions stand those which conspire to hold man back and keep him in a low stage of civilization. Omitting low altitude, which is important merely because of its effect on other factors, we are confronted by four chief conditions,—first, the prevalence of fevers; second, the prevalence of great heat and moisture almost without change from season to season; third, the difficulty of carrying on permanent, intensive agriculture and fourth, the relative ease of getting a living in the jungle.

Little by little the world is learning that the most dangerous diseases are not necessarily those which show the highest deathrate.

The plagues of the Middle Ages loom large in history, but they did not do a tithe as much harm as syphilis. Yellow and typhus fevers may decimate a population, but they are far preferable to the slow, irresistible ravages of recurrent malarial fevers which rarely seem to kill, but merely undermine the constitution, leaving both mind and body inefficient. Tuberculosis, in our own land, is so dreaded that we wage a crusade against it, but its dangers are probably far less than those of the insidious colds which year after year attack fully half of our northern populations, not killing them, not even doing more than spoil their work for a few days, and yet in the aggregate causing an incalculable amount of damage and giving an opening for a large part of our cases of consumption, diphtheria, deafness, and many other afflictions. Just as we, in our huge folly, long neglected consumption and still largely neglect the even more insidious ordinary colds, so the man within the tropics often ignores malaria. Again and again I have talked with people who said there was no fever in the particular place where they lived or that they had not had fever, but before the next meal they took a dose of quinine, and that same night, perhaps, they reeled with a touch of fever or shivered with a chill. They called it "nothing," but even quinine did not prevent them from being weakened by it. Few foreigners, especially children, can live long in the lowlands under ordinary conditions without being affected.

As for the natives, it is often stated that they become immune to fevers, but here is what Sir Ronald Ross, one of the chief authorities on the subject, has to say:

"These diseases do no affect only immigrant Europeans, they are almost equally disastrous to the natives, and tend to keep down their numbers to such a low figure that the survivors can subsist only in a barbaric state. To believe this one has to see a village in Africa or India full of malaria, kala-azar, or sleeping sickness, or a town under the pestilence of cholera or plague. Nothing has been more carefully studied of recent years than the existence of malaria amongst indigenous populations. It often affects every one of the children, probably kills a large proportion of the newborn infants, and renders the survivors ill for years. Here in Europe nearly all our children suffer from certain diseases—measles, scarlatina, and so on. But these maladies are short and slight compared with the enduring infection of malaria. When I was studying malaria in Greece in 1906 I was struck with the impos-

sibility of conceiving that the people who are now intensely inflicted with malaria could be like the ancient Greeks who did so much for the world; and I therefore suggested the hypothesis that malaria could only have entered Greece at about the time of the great Persian wars—a hypothesis which has been very carefully studied by Mr. W. H. S. Jones. One can scarcely imagine that the physically fine race and the magnificent athletes figured in Greek sculpture could ever have spent a malarious and spleno-megalous childhood. And conversely, it is difficult to imagine that many of the malarious natives in the tropics will ever rise to any great height of civilization while that disease endures amongst them. I am aware that Africa has produced some magnificent races, such as those of the Zulus and the Masai, but I have heard that the countries inhabited by them are not nearly so disease-ridden as many of the larger tracts. At all events whatever may be the effect of a malarious childhood upon the physique of adult life, its effects on the mental development must certainly be very bad, while the disease always paralyses the material prosperity of the country where it exists in an intense form.

"Consider now the effects of yellow fever, that great disease of tropical America. The Liverpool School sent four investigators to study it, and all these four were attacked within a short time. One died, one was extremely ill, and two suffered severely. The same thing tended to happen to all visitors in those countries. They were almost certain of being attacked by yellow fever, and the chances of death were one to four. Tropical America was therefore scarcely a suitable place for a picnic party! But malaria and yellow fever are only some of the more important tropical diseases. Perhaps the greatest enemy of all is dysentery, which in the old days massacred thousands of white men, and millions of natives in India, America, and all hot countries, and rendered survivors ill for years. Malaria has always been the bane of Africa and India; the Bilharzia parasite of Egypt; and we are acquainted with the ravages of kala-azar and sleeping sickness. Apart from these more general or fatal maladies, life tends to be rendered unhealthy by other parasites and by innumerable small maladies, such as dengue and sand-fly fever, filariasis, tropical skin diseases and other maladies, . . . True, we have many maladies in Europe, but in order to compare the two sets of diseases we should compare the death-rates. Whereas in England it is a long way below 20 per thousand per annum, throughout the tropics it is nearer 40 per thousand. In India alone malaria kills over a million persons a year, and dysentery and malaria kills many hundreds of thousands. I have seen places in which the ordinary death-rate remains at between 50 and 60 per thousand; others which were so unhealthy that they were being deserted by their inhabitants; and others, lastly, which were simply uninhabitable. What would people say if such a state of things were to exist in most villages in England, Scotland, and Ireland?"[1]

On the whole it seems safe to say that in tropical countries the

[1] *United Empire*, February, 1913, pp. 123–124. Sir Ronald Ross, "Medical Science and the Tropics."

density of population and the stage of culture depend to a large extent upon the amount and kind of fevers. Yet fevers are far from being the whole story. Few who have ever been in the torrid zone will deny that under prolonged and unvarying conditions of heat and dampness both physical and mental energy decline. One is tempted to sit down idly and rest and enjoy the warm air. When it is time for a new piece of work one tends to hesitate and to be uncertain as to just how to begin. Of course there are exceptions, and of course a long inheritance of activity in cooler regions will for years largely overcome these tendencies. Nevertheless of the scores of northerners, both American and Europeans, whom I have questioned in the torrid zone there was scarcely one who did not say that he worked less than at home. At first a considerable number said that they had as much energy as at home, but then they added that it was not necessary to work so hard, and moreover that they did not feel like it. Much more striking was the absolute unanimity with which they said that when they experienced a change of climate, especially if they went from lowlands to highlands, or still more when they returned to the north, they at once felt an access of energy which lasted some time after their return. To a New Englander accustomed to look upon our southern states as having a warm, debilitating climate, it is interesting to hear people in Guatemala speak of being stimulated as soon as they feel the cool winter air of New Orleans. The natives of the torrid zone are of course so accustomed to the heat that they enjoy it and suffer from even a slight degree of cold, but the very fact of being wonted to the heat seems to carry with it the necessity of working and thinking slowly. The universality with which this is recognized in Central America is significant. Again and again, when one asks about labor conditions in specific places, one is told, "Oh yes, the people there are all right, but you know it's always hot down there and they don't work much." All this, I know, is perfectly familiar, but it deserves emphasis because the great ruins are practically all in the hot country where "they don't work much."

In addition to debilitating fevers and an enervating uniformity of warm, moist atmospheric conditions, tropical countries suffer from

peculiar agricultural conditions. In the great forest such as that of Peten, where rain falls at all seasons, the making of clearings is practically impossible. In the dense jungle, such as that at an elevation of one to two thousand feet in the Pacific coffee belt of Guatemala, this is usually but not always possible. It depends on the length and character of the dry season in February, March, and April. Two or three weeks of steady sunshine are said to suffice to prepare the cut bushes and smaller branches of the trees for burning, but sometimes there is scarcely a rainless week during the whole year. This happened in 1913. People, who chanced to do their cutting early, burned their fields and were able to plant a corn crop, but many cut too late and failed. It is easy to say that everyone ought to cut and burn early, but in the first place the lethargy of the torrid zone leads people to put things off till the last moment. In the second place, if the land is burned over too early, weeds and bushes will sprout and grow to a height of a foot or two before it is time to plant the corn. Hence a second clearing will be necessary, and if a second burning is impossible the corn will be at a disadvantage.

This does not end the difficulties of agriculture in the dense jungle. Thanks to the abundant vegetation and constant rains or to the hot sun which causes rapid decomposition, or to some other unknown cause, many important chemical ingredients are quickly leached from the soil. Hence while the first corn crop is usually very abundant, the second, if it follows immediately after the first, is poor, so poor that it is scarcely worth raising. The regular custom is to cultivate a given tract one year, let the bushes grow four years, till they are perhaps fifteen or twenty feet high, and in the fifth year cut, burn, and plant again. Thus agriculture in the dense jungle is not only precarious, but it is forced to be extensive and superficial rather than intensive and careful. Therefore it does little to stimulate progress. In the drier regions, whether high or low, the soil is not so quickly exhausted, especially if the absence of roots or other conditions make it possible to turn up new soil by ploughing or otherwise. The crops are by no means so abundant as in the wetter places, but the same land can be cultivated year after year

with only short periods of rest. The cultivator must work harder than in the wet places, but his success is less precarious, the efforts of one year have a direct bearing on succeeding years, and permanent industry in encouraged.

Still another disadvantage of the low, wet regions needs to be briefly discussed. It is hard for mankind to get a living under any circumstances in the genuine tropical forest, and he must work at least moderately for one in the dry parts of tropical lands. In the big jungle, however, game is abundant, wild fruits ripen at almost all seasons, a few banana plants, palm trees, and yams will almost support a family, and if a corn crop is obtained at all, the return is large in proportion to the labor. Thus, so long as the population is not too dense, life is easy and there is little stimulus to effort. Under such conditions the density of population is not likely to increase, for only by a revolutionary access of skill and industry would it be possible to change from the easy, hand to mouth life of the present to the intensive, industrious life which would be necessary in order to support a dense population.

Thus far we have seen that the distribution of population in Guatemala to-day is unquestionably very different from what it was in the past. We have further seen that the physical conditions which make for density of population and increase of civilization are distributed in a peculiar fashion. They prevail in the highlands where there is no evidence that the civilization of the past was any higher than that of the present; and do not prevail in the lowlands where there is the clearest and most abundant evidence of the prevalence for many centuries of a civilization far in advance of that of to-day. Moreover the ancient civilization did not come to the country full-fledged as did that of Spain in later times. It did not do its finest work at once and then decline as did that of the Spaniards after they had built their massive old churches. On the contrary it apparently arose where we find its ruins, and it endured for centuries before it decayed. The most fundamental fact is not the great change which has taken place in the character of the Maya race. Nor is it the fall of Maya civilization, whether from internal decay or external attack. It is merely the simple fact that the

highest native American civilization grew up in one of the worst physical environments of the whole western hemisphere. Close at hand, in the Guatemalan highlands on one side, and in the dry strip of northern Yucatan on the other, far more favorable environments were occupied by closely allied branches of the same race, but the greatest civilization grew up in the densely forested, highly feverish, and almost untillable lowlands of Peten and eastern Guatemala.

The explanation of this peculiar state of affairs appears to lie in one or all of three things; first, the character of the Maya race; second, the relative abundance and virulence of various diseases; and third, the nature of the climate and its effect on forests, diseases, and agriculture. It is possible to adopt the usual unexpressed assumption of historians and to suppose that the original Mayas were stronger and more virile than any other race which has entered the torrid zone, and that because of some unexplained stimulus whose nature it is hard to surmise they flourished greatly for many centuries in a habitat in which modern races can barely subsist. The theory that the Mayas were different from other races has a good deal to commend it. They certainly were a remarkable people. The only question is how remarkable. The nearest analogue to their achievements is found in the ruins of Indo-China, Java, and Ceylon. In none of these cases, however, was the degree of success anything like so great as among the Mayas. The Asiatic races appear to have been like the Spaniards, invaders who did not develop a new civilization but brought their ideas with them from other places where we can still see remains of the parent culture. Moreover they did not rise to the height of inventing a method of writing, and, in Indo-China and Java at least, they appear to have had the advantage of tools of iron. Nevertheless, when their history is finally understood, we shall perhaps find that their civilization and that of the Mayas arose under similar conditions because of similar causes. This, however, is aside from the question. The important point is that no matter how capable we suppose the ancient Cingalese, Indo-Chinese, and Javanese to have been, the ancient Mayas were far more capable, for not only were the achieve-

ments of the Mayas greater than those of the others, but their opportunities were less. Hence, if we explain the rise of Maya culture solely on the basis of racial character we are forced to assume that the ancient Mayas were not only almost immeasurably in advance of any race that now lives under a similar environment, but were far more competent than any other race that has ever lived permanently in any part of the torrid zone. Indeed in their achievements in overcoming an adverse environment, we are perhaps obliged to put them on a pinnacle above any other race that has ever lived.

Without denying that the Mayas were a remarkable people, let us entertain the further hypothesis that in the days of their greatness tropical fevers either had not been introduced into America, or were by no means so virulent as now. This helps us greatly, for it relieves us of the necessity of assuming the Mayas to have possessed a degree of resistance to fevers far in excss of anything known to-day. There are, however, grave objections to this hypothesis. In the first place it is a pure assumption entirely unsupported by any independent evidence. In the second place, tropical diseases are numerous, and even malarial fevers are of several kinds. We may readily suppose that one or two diseases may have been introduced into Central America between the time of the Maya civilization and the Spanish Conquest, but in the entire absence of any evidence it is a rather large assumption to suppose that many diseases were thus introduced and that they were able to work so great a revolution. Thirdly, this hypothesis does not explain why the advancement of civilization went on so rapidly and for so long in spite of the enervating effects of almost unchanging heat and dampness. Nor does it explain why the Maya civilization reached the coast at only one or two spots. So far as topography is concerned there is nothing to prevent this on either coast. Much of the narrow Pacific plain could be cultivated with ease even though swamps do cover part of it, and on the Atlantic side the parts of the forest where there are no ruins seem to be no worse than those where they exist. The native inhabitants of this region all appear to have been of Maya stock, even though they may not have be-

longed to the main branch. Under such circumstances it hardly seems as if so progressive a civilization could have existed many centuries without extending its influence to the coast in British Honduras, unless there had been some preventive such as fever.

The assumption that in Central America tropical diseases were formerly less abundant or less baneful than now relieves us of the necessity of supposing that the Mayas, remarkable as they were, possessed a degree of immunity or resistance to disease far in excess of that of other races, but it does not relieve us of other difficulties. Moreover as it now stands it has the weakness of being a pure assumption with no assignable cause and no independent evidence. In order fully to explain the location of so high a civilization in Peten rather than in the highlands of Guatemala it seems necessary to supplement our assumptions as to the character of the Mayas and as to the prevalence of disease by the further assumption of a change of climate. The sort of change which would accomplish the required result would demand that at the height of Maya civilization climatic conditions should have been such that the forests of Peten would not be so dense as now, and hence that mosquitoes of the anopheles family would not be so abundant. In other words it would demand conditions like those which prevail to-day two hundred and fifty to three hundred miles north of Guatemala in the northern part of the peninsula of Yucatan. There the climate is to-day such that low jungle takes the place of dense forests. Mosquitoes of the anopheles species are rare. Malaria is comparatively unimportant. Thanks to these conditions the country is one of the most prosperous and progressive to be found anywhere within the tropics at sea-level. These favorable conditions are due to the fact that although heavy equatorial rains fall in summer and make the country fruitful, there is a long dry season during the winter and spring. If such conditions were to spread two hundred or three hundred miles southward into Peten that region would greatly change its character. Agriculture would still be subject to some handicaps, but would be nothing like so difficult and haphazard as at present. The areas of big jungle where life is excessively easy so long as the population is scanty, but where intensive agriculture

is to-day difficult would be reduced. Debilitating malarial fevers would prevail but little under such conditions, and the fact that Peten is a lowland, fertile and easily accessible, would make it a natural center of civilization. In other words if we adopt a climatic hypothesis of the kind here outlined, it does not lead us to abandon our other hypotheses as to the racial character of the Mayas, or as to the debilitating effects of disease. It simply supplies the elements which the other hypotheses lack.

The hypothesis of a change of climate in Guatemala by no means finds its only support in the considerations just set forth. On the contrary two independent lines of reasoning lead to the same conclusion. One of these is the existence of alluvial terraces in close connection with the ruins of Copan, and the other is the logical result of the investigation of ruins, lakes, and deserts in Asia, and of similar phenomena together with the growth of trees in North America. Both must be dismissed briefly. During the Pumpelly expedition sent out by the Carnegie Institution of Washington to Central Asia in 1903, Professor William M. Davis and the writer investigated a large number of alluvial terraces in mountain valleys from Persia eastward to Chinese Turkestan. From various lines of evidence set forth in the report[2] of that expedition they came to the conclusion that the terraces must be due to variations of climate. Otherwise they could scarcely occur with such a wide and regular distribution, and with such a minute adaptation to every valley no matter which way it sloped or how large it might be. Further study in the drier parts of the United States and northern Mexico as well as in Greece and Turkey seems to confirm this idea. It has been found, furthermore, that terraces of the same kind and apparently of the same climatic origin extend down into Southern Mexico and are well developed in the state of Oaxaca. In Guatemala the Motagua and other rivers are characterized by similar terraces which are described in full in the author's forthcoming volume on the "Climatic Factor" to be published shortly by the Carnegie Institution of Washington. It must suffice to say here that the famous

[2] "Explorations in Turkestan," Vol. 1, 1905, Carnegie Institution of Washington, Publication No. 26.

ruins of Maya culture lie upon a terrace of exactly this sort, while below the ruins there lies another similar terrace formed since the ruins were built. This seems to indicate that since the foundation of Copan, probably early in the Christian era, there has been a double climatic change whereby the Copan River, after having filled up its valley to the level of the upper terrace, was then impelled, first, to carry away material from the valley bottom, next to deposit new material, and again to carry it away. In other words the terraces seem to afford independent evidence that since the building of Copan the climate of Guatemala has been subject to distinct pulsations.

The other line of evidence is so complex that only the results can here be stated. From a prolonged study of ruins in dry places, roads and deserts which are now impassable, traces of springs where no springs now exist, elevated strands of enclosed salt lakes, and other lines of historic, archæological and physiographic evidences the writer has been led to believe that in central and western Asia, Greece, north Africa and perhaps elsewhere climatic pulsations have taken place during historic times. A study of similar lines of evidence in the United States under the auspices of the Carnegie Institution in the years 1910–1912 led to a similar conclusion here. Finally still another independent line of research was adopted, namely the measurement of the rate of growth of the giant sequoia trees of California which grow in a region where the thickness of the rings depends largely upon the amount of rainfall. This led to the same conclusion, namely that pulsatory changes of climate have taken place to a marked degree during the past three thousand years. The nature of the change has been inferred from various sources, especially from a comparative study of the meteorological records during years when the trees of California grew rapidly or slowly during the last half century. From this it appears that moist periods in regions like Persia, Greece or Arizona are probably due to the fact that the cyclonic storms of winter not only move farther south than usual and hence are uncommonly frequent in those countries but perhaps begin earlier in the fall and last longer in the spring. This, of course, reduces the length of the dry season in summer.

Farther south in the torrid zone, however, the effect would appear to be the exact opposite. That is, if the belt of cyclonic storms is pushed equatorward in winter it would seem to mean that the belt of sub-tropical high pressure and drought whence the trade winds take their rise is also pushed equatorward. Thus during the winter the dry conditions of the semi-arid or desert belt which encircles the earth at about latitude 25° to 30° would be pushed farther toward the equator. The result of this would seem to be to force the trade winds so far south during winter that they would not have their present effect in causing rainfall throughout practically the whole winter in Peten. On the contrary, there would be a dry season of several months duration such as now prevails in Yucatan and in the Guatemalan Highlands. This would prevent the growth of forests and cause them to be replaced by jungle or bush. Here again, then, a third line of evidence appears to point to a pulsatory climatic change which would produce results in accordance with our first assumption.

Here we must let the matter rest. The theory of changes of climate involves so many historic and economic consequences that it demands most careful consideration. Perhaps it is possible to explain the peculiar location of the ancient Maya civilization on some other hypothesis, but thus far no other seems to be supported by so much independent evidence. The acceptance of the climatic theory does not oblige us to change our ideas as to the remarkable character of the Mayas, or as to the causes of the development of civilization. It merely provides conditions under which it becomes probable rather than merely possible that a race might have developed. In other words it removes the great difficulties of agriculture. It provides a habitat which to a certain extent would be more free than at present from the debilitating influences of heat and moisture; and it does away with the conditions that now cause such terrible fevers. In all these ways, then, while it does not conflict with accepted ideas as to the historic development of civilization, it removes some of the difficulties in the way of accepting those ideas.

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THE CORRELATION OF STRUCTURE AND FUNCTION IN THE DEVELOPMENT OF THE NERVOUS SYSTEM.

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(*Read April 18, 1913.*)

Catch phrases sometimes creep into scientific literature where their presence may be as insidiously suggestive of the possession of imaginary stores of knowledge as they are when employed in the description of current events. We have for example become so accustomed to affirming the history of the individual reproduces in miniature the history of the race that we are often in danger of assuming a greater degree of familiarity with the details of ontogenesis than is warranted by a careful survey of the facts. Our knowledge of the primitive reactions of the higher organisms in relation to synchronous structural conditions is still so meagre that it has scarcely risen above the stage of conjecture and cannot be presented in the form of organized experience. Although it is not necessary to actually question the validity of a very useful hypothesis, based upon the similarity of the more striking features in ontogeny that are paralleled by the chief events of phylogenetic development, there is nevertheless adequate reason for emphasizing the necessity not only for more careful study of the correlation of events in the structural and functional growth of the higher organisms, as fundamental to a more comprehensive understanding of the nature of nervous reactions, but also as a method of determining the factors of individual behavior.

Efforts have already been made by a few investigators to try and study the relationships existing between the structural conditions existing at certain epochs, and the character of the synchronous responses of the embryo. The observations of Wintrebert, probably among the first to be recorded in the discussion of these special problems, were not by any means as extensive or as carefully planned

as the work carried on by Coghill, which will unquestionably form a basis for future studies of importance.[1] Some of the results of my own observations along these lines have been referred to in three papers.[2]

Before attempting to continue the description of the details of my own investigations I wish to call attention to the variety as well as importance of the problems awaiting solution in this special field of enquiry. Many problems of phylogeny naturally suggest the consideration of questions relating to the correlation of structure and function. We find a parallel for the succession of events in racial development in the ontogenetic sequence or the life-history of the individual, in which are revealed a chain of phenomena much better adapted for detailed study than those occurring in the former and, what is of still greater importance, is that the latter are to a certain extent under the control of the investigator. The comparative rapidity with which individuals pass through the various stages in development is also a factor facilitating enquiry.

What is particularly needed at present is a careful systematic study of the initial responses in the lives of embryos, representing several different species of animals, and a record of these phenomena which is sufficiently detailed to indicate the relationship existing between the physiological events and the changes taking place within the nervous system. Unfortunately investigators have long been hampered by the compelling desire to attempt to solve the problems relating to the complex nervous system of the adult before considering the simpler correlations possible in the early life of the embryo.

Among the primitive adjustments of all organisms those for temperature variations naturally play a very important rôle, and this is only what might be inferred when we reflect upon the fact that the responses of living beings to heat and cold are fundamental properties of all living matter. The reactions recurring in response to thermic stimuli, before the development of the nervous system, present some interesting features. It has long been known that

[1] *J. Comp. Neurol.*, Vol. 19, 1909.

[2] *Mittheil. a. d. Zoolog. Station*, 2, Neapel, 18 Bd., 2–3 Hft., 1907; *J. Comp. Neurol.*, Vol. 21, No. 4, August, 1911; *J. Experiment. Zool.*, Vol. 11, No. 4, Nov., 1911.

living embryos when placed in various solutions respond with great rapidity to even relatively slight temperature changes occurring in the surrounding media. In the case of the pulsation of the heart many investigators, among whom are Snyder, Carlson, v. Tschermak, and others, determined the temperature coefficient in connection with the activity of this organ. As far as I have been able to determine the extreme sensitiveness of the heart as regards rises in temperature seems to be somewhat greater, or at least the responses are quicker, at a period when the development of the nervous system is well advanced than at earlier stages in the life of the embryo; and I believe the same law holds true with regard to other reactions of the organism. These facts afford an interesting confirmation of the results of observations made by A. G. Mayer with a view to determining the relative importance of the nervous system in the medusa. Mayer has shown that there is greater sensitivity for heat when the muscles remain in contact with the sense-organs than when the connections are severed. The general character of the responses of the embryo in regard to heat, prior to or subsequent to the development of the nervous system, are in a measure comparable to the variations of adjustment of jellyfish for similar stimuli when muscles are either deprived of connection with or allowed to remain in contact with sense organs. In the vertebrate embryo as well as in the medusa the extreme delicacy of response is dependent upon the presence of nerve-elements, and when these have not developed or have been eliminated by experiment the capacity of adaptation of the organism is correspondingly lowered.

The technique used in the experiments is the same in all cases. The chief precaution necessary is to avoid as far as possible subjecting the embryos to changes in temperature and all rough handling; so that the results may not be complicated by the introduction of too many different stimuli.

When the eggs are taken out of the incubator they are opened as quickly as possible, just inside the door of the warm box which covers the microscope, and the embryos are detached from the egg and lifted by means of a horn spoon into the dish containing the solution ($NaCl$ 0.9 — $CaCl_2$ 0.02 — KCl 0.02 — $NaHCo_3$ 0.02 —

glucose 1 per cent., bouillon 10 per cent.). After a little practice the operation of removing the embryo from the egg and placing it in the dish, without either delay or unnecessary shock, may be easily performed. It is obvious that stimuli of a purely mechanical nature up to a certain degree of intensity seem to be less injurious than those caused by variations in temperature.

The effect of rapid changes in position upon the action of the heart during the period represented by embryos of from 12–16 somites is almost a negligible quantity. Embryos that were whisked rapidly about in a dish by means of a camel's hair brush showed no disturbance of cardiac activity; provided of course that the temperature of the solution in which they were placed remained constant.

The primitive responses of these organisms show certain interesting features when elicited in response to various chemical substances used as irritants. In this connection the action of a number of different substances was observed, while that of two was studied in detail. The substances selected for more detailed investigation were strychnia sulphate, an important inorganic nerve stimulant, and thyroid extract, representing organic substances toxic for nervous tissues. After it became possible to eliminate the error attributable to such slight differences in temperature as are apt to occur during manipulation it was found that these two dissimilar substances were strikingly alike in their physiological action upon the heart, if used at a time prior to the development of the nervous system. Even when employed in minute quantities the characteristic accelerating action upon the heart was not observed. As will be noticed in studying the records in the case in which the smallest doses were administered the rate of the cardiac pulsations was not disturbed for some time and only after the elapse of from one to two hours did the action of the heart begin to show symptoms of sagging. In all cases an accelerating action seemed to be entirely absent.

Probably the most intimate correlation which we have yet been able to establish is in connection with the development of the peripheral nervous system. In the case of such substances as cocaine and eucaine we have already shown (*op. cit.*) that there is no inhibitory and reversible action in selachian embryos following ordinary

doses of these drugs until the peripheral nervous system is developed. We find the action of thyroid extract as well as strychnine is modified to some extent by the development of the sympathetic nervous system; an occurrence taking place about the fourth day. We are not yet prepared to state exactly what the character of this mechanism is, although for the present we may consider it highly probable that the increased activity of the heart brought about by moderate doses of the two substances mentioned is the result of the functional activity of the sympathetic system. The symptoms of irregularity in the heart's activities which develop after a certain period deserve consideration and show a remarkable degree of similarity for both strychnia, thyroid extract and magnesium chloride. As will be noticed in chick no. 3 the rapidity of the heart decreased after the embryo was placed in a solution containing thyroid extract. Suddenly, and this seemed to be the characteristic effect of all the substances used—the organ stops pulsating, remaining motionless for a period varying, as a rule, from ten to thirty seconds, or even two minutes. Then it suddenly begins to pulsate again, the rhythm gradually increasing in strength and rapidity until a point of maximum intensity is reached and then after one-half or one minute the cycle ends again. The abrupt manner in which the pulsations cease and the subsequent incidence of the beats, often after prolonged intervals of rest, are strikingly similar to the phenomena taking place when an embryo has been poisoned by an excess of magnesium chloride. In these early stages of development it is extremely interesting to compare the action upon the heart of three substances, possessing chemical qualities as different as thyroid extract, magnesium chloride and strychnine sulphate. The characteristic primary toxic effects as shown in the adult by the rapid rhythm of the heart do not appear until the period when the nervous system has attained a relatively high degree of differentiation.

In addition to the substances already mentioned, solutions of NaOH (1:500) and CH_3OOH (1:500–1:1,000) were employed. No positive results, except a gradual slowing of the heart, were noted in connection with the former, but the latter seemed to exert a marked inhibitory action upon the heart; the stronger solutions

rapidly, and the weaker ones slowly but surely blocking the rhythm. Solutions of adrenaline (1:4,000) and epinine (1:2,000) produced symptoms similar to those following the use of thyroid (1:10,000).

Some of the details of the experiment are given in the following records:

Chick No.	Somites.	Time.	Heart-beats.	Solution.	Results.
1	13	10.7 A.M.	54	Ringer and (1:500)CH_3OOH	
		.11	66		
		.25	—	——	No heart beats.
2	15	12.26 P.M.	96	Ringer and (1:1000)CH_3OOH	Temperature of fluid above normal.
		.28	69		
		.31	78		
		.33	66		
		.40	78		Rises and falls in heart rate due to temperature changes.
		.45	66		
		.47	75		
		.50	70		Contraction of heart was shallow and snappy.
3	13	10.17 A.M.	52	Ringer and Thyroid (1:10,000) at 10.22	
		.23	48		
		.30	48		
		.45	48		
		11.06	51		
		.16	48		
		.57	51		
		12.31 P.M.	54		
		1.00	44		
		.35	36		
		2.11	33		Pulsations very weak but regular.
4	13	3.50 P.M.		Ringer's solution alone	
		.54	26		
		4.00	42		
		4.20	42		
		.57	42		
		5.35	42		
		.47	42		Heart beating very feebly.
		9.30	60		
5	14	4.35		Ringer and Thyroid (1:15,000)	
		.37	72		
		5.00	72		
		.44	60		
		.53	60		
		10.00	48		Individual pulsations strong, but broken by periods of complete rest.

The special instances which we have cited are a few taken from a long list of experiments and the results as given may be considered to be characteristic of all the cases observed. It is quite unnecessary to repeat in detail the experiments in which strychnia sulphate was used as the results for solutions varying in strength from 1:5,000 to 1:10,000 practically corresponded with the records for thyroid extract.

An extremely interesting field of work lies in the direction of determining with more exactitude than has yet been done the varying degrees of responsiveness of the organism to these toxic agents at different periods in the early development of the embryo. An exceedingly complicated problem but one of great importance would be the determination, if possible, of the change in the symptoms as the embryo develops and the probable progressive increase in the permeability of the cells for the different solutions. This question must be solved before we can appreciate the character of the changes in the reactions taking place within the organism when the control of functions is taken over by the nervous system.

Princeton University,
April 18, 1913.

RELIEF MAP OF THE TERRESTRIAL GLOBE.

Illustrating the relations of the mountains to the sea, which has uplifted great walls along the borders of the Continents, by the expulsion of lava from beneath the ocean and its injection under the land. This impressive view of the Earth shows at a glance that the mountains have been formed by the Sea. From Frye's *Complete Geography*, by permission of Ginn & Co., Publishers.

FURTHER CONSIDERATIONS ON THE ORIGIN OF THE HIMALAYA MOUNTAINS AND THE PLATEAU OF TIBET.

(PLATES XXIII–XXXIII AND XXVII *bis* AND XXXI *bis*.)

BY T. J. J. SEE.

(*Read April 18, 1913.*)

I. INTRODUCTORY REMARKS.

The four memoirs dealing with the cause of earthquakes, mountain formation and kindred phenomena connected with the physics of the earth, which the writer had the honor to communicate to this Society in the years 1906–08, and have published in the *Proceedings*, have laid the foundations of a new theory of the physics of the earth's crust. The new theory already is widely adopted by the most eminent investigators, and the purpose of the present paper is merely to add a final confirmation of some interest.

During the past five years the writer's attention has been so fully occupied with the problems of cosmogony that the problems relating to geogony, or the formation of the earth, have been left largely in abeyance; and yet some new light has been shed on them, especially by the researches showing that the lunar craters are due to impact, and thus in no way similar to terrestrial volcanoes, as was so long believed.

Quite recently it was thought worth while to reëxamine the phenomena of the earth's crust, in the light of the new science of cosmogony, resulting from the researches of the past five years. For in studying the problem of the origin of the Himalayas and the plateau of Tibet some important considerations were brought out that were not included in my former papers, and thus it seems advisable to place them on record as confirming and extending my former investigations.

Moreover, the subject of the origin of the Himalayas is attracting attention abroad. Apparently without knowledge of my work* Colonel Sidney G. Burrard, R.E., F.R.S., surveyor-general of India, has been devoting considerable attention to the subject in "Professional Paper No. 12, Survey of India," a summary of which is given in *The Observatory* for November, 1912, p. 413:

> "It may be remembered that several years ago Col. Burrard showed that there appears to be a subterranean mass of great density lying across India in mean latitude 23° North. He now shows that the observations indicate the existence of a line of low density between this subterranean mass and the Himalayas, and suggests that there was, or is, one long crack in the earth's subcrust extending from Sumatra round the Arrakan coast across northern India, through the Persian Gulf to the Mediterranean, traces of which are seen in the parallel shores of the Gulf of Oman and the Persian Gulf. The crack has been filled with alluvial deposit across Northern India and in other places, but the Himalayas remain as the result of the rift in the earth, a great mass of matter having been pushed northward. It has been supposed by others that the Himalayan range was formed by the southward advance of the northern part of the Asiatic continent on to the Indo-African tableland."

The idea here developed by Colonel Burrard, including especially the light material under northern India, and the pushing of the Himalayas northward, is so very similar to that developed in my memoirs that it must be regarded as an independent confirmation of the theory that the mountains are formed by the sea. And as this conclusion applies to the greatest and most intricate range in the world, the external relations of which are not entirely simple, I deem it worthy of attention.

Finally, it may be noted that much interest has been awakened in this subject in England and other countries of Europe. The new theory already is widely taught in the schools of Great Britain and the continent; and in his new work "The Growth of a Planet" (The MacMillan Co., New York, 1911), the London geophysicist Mr. Edwin Sharpe Grew, M.A., concedes that the author's reasoning on the Aleutian Islands is unanswerable, and finally says:

* Since this paper was written Colonel Burrard informs me that to his regret he had not seen the papers of 1906–8, and seems to regard the new theory as quite well established.

"Dr. See has arranged his facts with great ingenuity, and the presentation of his case is the most powerful argument which has ever been advanced in favor of the view held since the days of Strabo, Aristotle or Pliny, that the expansive force of steam is the prime cause of volcanic and seismic disturbances."

In view of this general interest a few additional considerations on the origin of the Himalayas may be important. For after careful reflection I regard the Himalayas as the crucial test; and as the theory is triumphantly verified by a more complete study of this great range, it must hereafter be regarded as firmly and permanently established.

2. The Volumes of the Plateaus of the Rocky Mountains, of the Andes, and of the Himalayas.

In the four memoirs included in the *Proceedings* of this Society for 1906–08, the new theory of mountain formation is treated with considerable detail, but some numerical relations between the plateaus above mentioned are worthy of more attention than they have yet received.

The Pacific plateau of North America is of variable width, being less than 500 miles wide in Mexico, and perhaps 600 miles wide in Canada, but from 1,000 to 1,500 miles wide in the United States. Perhaps 750 miles wide would be a good average estimate of the whole plateau. And the height may be taken as approximately 5,000 feet, or a mile above the sea. These average figures will satisfactorily represent the Pacific plateau in North America. It is noticed also in many places that where the plateau is broadest it is of less average height; but where it is narrower the height is somewhat increased.

In the Andes the same principles prevail. The plateau is highest in the region of Lake Titicaca, where the elevation is over 12,600 feet, or 2.5 miles. The width here does not exceed 300 miles. Further north, near Quito, it narrows up, and is not over half this width; but in Colombia it again spreads out to a width of 300 or 400 miles, but is only about 6,000 or 8,000 feet in height, scarcely more than half that along the more southern portion of the Andes.

It is noticeable that the height decreases from 12,600 feet near Lake Titicaca, to 11,000 feet in central Peru, and perhaps 10,000 feet at Quito; while south of Titicaca the height does not decrease appreciably till central Chile is reached, after which it falls steadily till the continent sinks beneath the sea at Cape Horn.

Now it is remarkable that if we take a typical section of the highest and broadest part of the Andean plateau, 2.5 miles high by 300 miles wide, the numerical product of width by height in miles is 750. And the Rocky Mountain plateau, 1 mile high and 750 miles wide, gives the same product, 750 square miles.

To be sure this product can be varied considerably by taking different sections of the plateaus of North and South America, but all in all this average estimate appears to be a fair one. For in the article "Andes," in the encyclopedia Britannica, 9th edition, Sir Archibald Geikie estimates the bulk of the Andes as of the average width of 100 miles, and height of 13,000 feet. The present estimate gives greater width but somewhat less height.

On the whole, I am inclined to think that the average sectional volume of the Andes is somewhat less than that in the Rocky Mountain plateau; for between Colorado and the Pacific coast the width is about 1,500 miles, and the average height about a mile. The plateau is much narrower in Canada, and very much narrower in Mexico, practically disappearing entirely in Central America and Panama. Thus at one point in the United States the sectional contents may be twice that in the Andes; yet the average sectional volume for the Pacific plateau of North America is not much greater than the larger sectional volumes for the plateau of the Andes.

The significance of this equality in the volumes of the two plateaus lies in the fact that both are the product of the common Pacific Ocean, one in the northern, the other in the southern continent. The new theory does not require that the volumes should be exactly equal, but it implies that they should be comparable, and such is the fact in a very striking degree.

Let us now consider the plateau of Tibet, in comparison with that of the Andes. The height of western Tibet is about 15,000

feet, while eastern Tibet has an elevation of only 11,000 feet. The breadth also varies from some 200 miles on the West to 500 miles at the eastern extremity (General Strachey, article "Himalayas," Encyclopedia Britannica, 9th edition).

Accordingly, if we take the wider part of western Tibet as having a sectional height of 3 miles and a breadth of 250 miles, the product in miles is 750, exactly the same as in the Andes and the Rocky Mountains. Further east in Tibet the width may be 500 miles, and the height about 2 miles, which gives a sectional product of 1,000. This is larger than the average Andean product adopted above, and more like that of the Rocky Mountain plateau west of Colorado.

But the circumstance that the sectional volumes of three great plateaus in the three leading continents of the globe should all be so nearly equal is fully as impressive a fact as the related fact that all of these plateaus should overlook the same great ocean by which they were elevated.

Altogether the similarity in the volumes of sections of these three greatest plateaus is so striking as to make it difficult to deny that it constitutes practically a mathematical demonstration that these plateaus were uplifted by the Pacific Ocean. The relationships here brought out as to the volumes of these plateaus, in addition to the situations about the Pacific Ocean could not well be accounted for by chance, even if we did not know the cause of mountain formation. But as the cause of mountain formation is fully understood, the cause which has built the plateaus is also clearly shown, and it is impossible to consider any other explanation than that here outlined.

3. General Law that where a Continuous Plateau Increases in Width, it Decreases in Elevation.

This law doubtless results from the process of uplifting by which the mountains and plateaus have been raised above the sea. For example, in case of the continuous plateau crowned with mountain crests which surrounds the Pacific Ocean from Cape Horn to Alaska, and then extends down the southeastern shores of Asia,

runs westward through India, and down the east shore of Africa to the Cape of Good Hope, it is observed in each of the four continents traversed that where the plateau is highest it usually narrows in width, and *vice versa*.

Thus we have seen that the plateau of the Andes is high in Chile, Bolivia, Peru and Ecuador, but in Colombia falls to about half its former level, and expands to about double width. This expansion of the width of the plateau in Colombia is characteristic of plateau formation in general. There are slight exceptions to the rule, but the conformity to it is much more noticeable. For example, at Titicaca the width is about 250 miles, but some distance north of this region the Andean Plateau seems to narrow up till the width scarcely exceeds 150 miles, in Ecuador; but it then spreads out again as the range enters Colombia.

It is not easy to explain this narrowing of the range, unless the great width and great height at Titicaca are due to the indentation of the coast at this point, giving uplifting forces from both directions, at the same time. This explanation seems to be well founded, and is confirmed by the corresponding effect north of central India, where the plateau of Tibet reaches its maximum elevation.

Accordingly, we probably should conclude that the width of the Andean plateau is normally less than at Lake Titicaca, and that the width there is due to a combination of forces from the two lines of coast, meeting at an angle of about 135°. It is therefore a fact in South America that wherever the plateau is widest, it decreases in elevation, as in Colombia.

In this problem of uplift, however, something depends on the depth and width of the adjacent elevating ocean, and thus a certain amount of variety should result. Since the adjacent sea is not of uniform effectiveness, we should expect minor deviations from the law; but obviously they should not be too pronounced.

In North America, the same general law holds true. Wherever the plateau is narrow, as in central Mexico, the elevation is great; but where it is wide, the elevation generally is lower. There are of course some exceptions to the rule, but it generally holds true.

For example, along the Rocky Mountain range the highest part

of the plateau probably is in Colorado, where the whole Pacific plateau is widest; but this only indicates that the forces which raised such high mountains as Pike's Peak also raised a high plateau in the general region, independent of the width of the plateau afterwards elevated from the sea. And so on generally.

The rule that the plateau decreases in height when it increases in width, must be understood to apply to a region of not too great width. For when the width is very great, we have rather a series of plateaus added together side by side than a single one; and the final result is a composite effect, one *plateau section* fitting onto another, and the whole series of sections running together as an unbroken embankment of variable height.

In view of these considerations, a plateau so wide as that between Colorado and California is really a series of plateaus, each of unusual width at this point, and the whole effect therefore a very broad compound plateau. The entire Pacific Plateau is the cumulative work of the ocean, done in successive sections; and as the ocean is deepest opposite California, the uplift naturally has been greatest in this part, which also developed the Sierra Nevada Mountains, and at a still earlier stage the Wasatch range in Utah.

The history of the building of the Pacific plateau from Colorado to California is too long to be described here, but these hints on the method by which it was elevated give some idea of the growth of the continent westward from the ancient border which was east of the present Rocky Mountain range.

4. The Cause of the Great Height of the Plateaus of Western Tibet and Titicaca.

Since writing the memoirs of 1906–08, I have had occasion to reëxamine the relationships of the great mountains to the plateaus, and of the plateaus to the sea, with the result of confirming in the most conclusive manner the uplift of the plateaus by the ocean. It is found that the plateau of western Tibet has almost exactly the relationship to the ancient sea valley formerly covering northern India, that the plateau of Titicaca now has to the border of the Pacific Ocean.

If we examine a good map of northern India, we shall find not only that the Indus and Ganges now flow in the ancient sea valley formerly depressed below the waves, and now elevated less than 1,000 feet above the ocean; but also that this valley made a sharp bend in north central India. It has the form of the Greek letter lambda, Λ, with the Ganges leg of the lambda by far the longest, and the included angle about 105°.

If the lava expelled from beneath this ancient sea valley came from two directions, at such an angle, the forces of uplift naturally would accumulate at the head of the Sea Valley. For they would come from the southeast and also from the southwest, as well as from the south; and the result of compounding these forces would be magnified forces of unusual intensity, directed to the elevation of the Himalayas of north central India. This is exactly what has taken place; and hence we see why the plateau of Tibet is so high in the western part of that great "roof of the world."

If now we turn to the region of Lake Titicaca, in South America, we find an exactly similar relative situation. The coast from the south and northwest meet at an angle of some 135°; and the forces producing the uplift have come from the two directions; and also from the west. The result has been a convergence of the forces tending to produee an uplift; but as the angle of 135° is less acute than in northern India, where the angle is 105°, it is not remarkable that the plateau of Titicaca is less elevated than that of western Tibet, where the forces converged more powerfully and were so compounded as to produce the maximum elevation.

It certainly is not accidental that these two highest plateaus of the world stand in *similar centers of converging forces directed from the ocean;* and that the higher plateau of Western Tibet has the forces converging at the smaller angle of 105°, and therefore compounding more effectively to produce a greater power of uplift, for equal energy directed from the side of the sea.

And as the observed phenomena confirm the theory in every detail, one finds it very difficult to believe that any other cause has shaped these stupendous uplifts of the earth's crust.

It is also easy to see why the heights of the plateau of Tibet is

less towards the east, where the elevation is only 11,000 feet. For in the eastern part only a side pressure was available for the uplift, and the forces of elevation did not converge towards a point, as in western Tibet and near Lake Titicaca, in Bolivia.

5. Some Phenomena Connected with the Great Earthquake at Arica, August 13, 1868.

One of the most important means of judging of earthquake phenomena is the evidence afforded by eye witnesses; and this becomes especially valuable when we know the nature of earthquake processes, because it then becomes possible to see in the descriptions given by eye-witnesses a certain amount of new meaning.

Accordingly, we add a brief account of the terrible earthquake at Arica, August 13, 1868, which was a continuation of the movements directly concerned with the uplift of the plateau of Titicaca. For it was a survival of the ancient movements which brought about this elevation, and as the region still is near the sea, it is of special interest, because it bears on the elevation of the plateaus of the Himalayas, now further inland.

In his "Light Science for Leisure Hours," p. 199, the late Professor R. A. Proctor describes the havoc wrought by the earthquake at the neighboring town of Arequipa as follows:

"At five minutes past five (P. M.) an earthquake shock was experienced, which, though severe, seems to have worked very little mischief. Half a minute later, however, a terrible noise was heard beneath the earth; a second shock more violent than the first was felt; and then began a swaying motion, gradually increasing in intensity. In the course of the first minute this motion had become so violent that the inhabitants ran in terror out of their houses into the streets and squares. In the next two minutes the swaying movement has so increased that the more lightly built houses were cast to the ground, and the flying people could scarcely keep their feet. 'And now,' says Von Tschudi, 'there followed during two or three minutes a terrible scene. The swaying motion which had hitherto prevailed changed into fierce vertical upheaval. The subterranean roaring increased in the most terrifying manner: then were heard the heart-piercing shrieks of the wretched people, the bursting of walls, the crashing fall of houses and churches, while over all rolled thick clouds of a yellowish-black dust, which, had they been poured forth many minutes longer, would have suffocated thousands.' Although the shocks had lasted but a few minutes, the whole town was

destroyed. Not one building remained uninjured, and there were few which did not lie in shapeless heaps of ruins."

This description was drawn for the phenomena observed at Arequipa, but that it would serve equally well for Arica is sufficiently indicated by the accompanying photographs of the town as it was before and after the earthquake. A more terrible record of desolation could hardly be imagined.

With this brief but striking description of the earthquake, we may now turn to the seismic sea wave at Arica, and here I shall again quote Proctor's account, which is based on the elaborate technical memoir prepared by Professor F. Von Hochstetter in the *Sitzungsberichte* of the Vienna Academy of Sciences for 1868, Vol. LVIII., Abth. II. Proctor's account runs thus:

"At Arica the sea wave produced even more destructive effects than had been caused by the earthquake. About twenty minutes after the first earth-shock (*i. e.*, 5:25 P. M.) the sea was seen to retire, as if about to leave the shores wholly dry; but presently its waters returned with tremendous force. A mighty wave, whose length seemed immeasurable, was seen advancing like a dark wall upon the unfortunate town, a large part of which was overwhelmed by it. Two ships, the Peruvian corvette *America* and the United States 'double-ender' *Wateree* were carried nearly half a mile to the north of Arica, beyond the railroad which runs to Tacna, and there left stranded high and dry. This enormous wave was considered by the English Vice-Consul at Arica to have been fully fifty feet in height.

At Chala, three such waves swept in after the first shocks of earthquake. They overflowed nearly the whole of the town, the sea passing more than half a mile beyond its usual limits.

At Islay and Iquique similar phenomena were manifested. At the former town the sea flowed in no less than five times, and each time with greater force. Afterwards the motion gradually diminished, but even an hour and a half after the commencement of this strange disturbance, the waves still ran forty feet above the ordinary level. At Iquique, the people beheld the inrushing wave whilst it was still a great way off. A dark blue mass of water, some fifty feet in height, was seen sweeping in upon the town with inconceivable rapidity. An island lying before the harbor was completely submerged by the great wave, which still came rushing on, black with the mud and slime it had swept from the sea bottom. Those who witnessed its progress from the upper balconies of their houses, and presently saw its black mass close beneath their feet, looked on their safety as a miracle. Many buildings were indeed washed away, and in the lowlying parts of the town there was a terrible loss of life. After passing far inland the wave

slowly returned seawards, and strangely enough, the sea, which elsewhere heaved and tossed for hours after the first great wave had swept over it, here came soon to rest.

At Callao a yet more singular instance was afforded of the effect which circumstances may have upon the motion of the sea after a great earthquake has disturbed it. In former earthquakes Callao has suffered terribly from the effects of the great sea-wave. In fact, on two occasions the whole town has been destroyed, and nearly all its inhabitants have been drowned, through the inrush of precisely such waves as flowed into the ports of Arica and Chala. But upon this occasion the center of subterranean disturbance must have been so situated that either the wave was diverted from Callao, or more probably two waves reached Callao from different sources and at different times, so that the two undulations partly counteracted each other. Certain it is that although the water retreated strangely from the coast near Callao, insomuch that a wide tract of the sea-bottom was uncovered, there was no inrushing wave comparable with those described above. The sea afterwards rose and fell in an irregular manner, a circumstance confirming the supposition that the disturbance was caused by two distinct oscillations. Six hours after the occurrence of the earth-shock, the double oscillations seem for awhile to have worked themselves into unison, for at this time three considerable waves rolled in upon the town. But clearly these waves must not be compared with those which in other instances had made their appearance within half an hour of the earth-throes. There is little reason to doubt that if the separate oscillations had reinforced each other earlier, Callao would have been completely destroyed. As it was, a considerable amount of mischief was effected; but the motion of the sea presently became irregular again, and so continued until the morning of August 14, when it began to ebb with some regularity. But during the 14th there were occasional renewals of the irregular motion, and several days elapsed before the regular ebb and flow of the sea were resumed."

In this excellent account of the great sea wave at Arica, August 13, 1868, Proctor makes no allusion to the U. S. S. *Fredonia,* which was lying at anchor with the *Wateree;* and we add therefore that the *Fredonia* is reported to have been capsized as the wave advanced, and nothing was ever again heard of her, all the officers and crew having been lost with the wreck of the vessel.

The *Wateree* was but little injured, and afterwards used as a hotel. The picture of the stranded *Wateree* here reproduced was made by an officer who visited the scene sometime after the disaster. This valuable historic photograph has been preserved by Mrs. E. V. Cutts, of Mare Island, to whom the author is indebted for this impressive illustration of the effects of this great sea wave.

The previous illustrations show the city of Arica before this earthquake, and the mere wreckage which remained after the innundation of the sea.

In an earlier passage than that above cited, Proctor quotes the description of an eye witness, which tells of the movements of the ships:

"The agent of the Pacific Steam Navigation Company, whose house had been destroyed by the earth-shock, saw the great sea-wave while he was flying towards the hills. He writes: 'While passing towards the hills, with the earth shaking, a great cry went up to heaven. The sea had retired. On clearing the town, I looked back and saw that the vessels were being carried irresistibly seawards. In a few minutes the sea stopped, and then arose a mighty wave fifty feet high, and came in with a fearful rush, carrying everything before it in terrible majesty. The whole of the shipping came back, speeding towards inevitable doom. In a few minutes all was completed—every vessel was either on shore or bottom upwards.'"

6. Pratt's Reasoning on the Density of the Matter Under the Ocean, Plains and Mountains, and its Application to India and the Himalayas.

Pratt's reasoning in regard to the density of the matter in and beneath the crust of the earth, and its bearing on the new theory of earthquakes is described in my paper on "The Cause of Earthquakes, Mountain Formation and Kindred Phenomena Connected with the Physics of the Earth," published in the *Proceedings* of this Society for 1906, pp. 344–346. His main conclusion is stated thus:

"This (deflection of the plumb line) shows that the effect of variations of density in the crust must be very great in order to bring about this near compensation. In fact the density of the crust beneath the mountains must be less than that below the plains, and still less than that below the ocean-bed" (Pratt, "Figure of the Earth," 3d edition, Art. 137, pp. 134–135).

Again:

"The conclusion at which we have arrived in Art. 137, that the parts of the crust below the more elevated regions are of less density, and the parts beneath the depressed regions in the ocean are of greater density than the average portions of the surface, seems to bear additional testimony to the fluid theory. For it shows that notwithstanding the varied surface, seen at present in mountains and oceans, the amount of matter in a vertical prism

drawn down at various places to any given spheroidal stratum is the same, although its length varies from place to place as the earth's contour varies" (idem., p. 162).

This subject of the density of the matter hidden from our view beneath the crust of the earth has also been discussed by the late Professor Henri Poincaré, in an address on "French Geodesy," translated by Professor George Bruce Halstead, and published in the *Popular Science Monthly* for February, 1913. The eminent French geometer reasons as follows:

"But these deep-lying rocks we cannot reach exercise from afar their attraction which operates upon the pendulum and deforms the terrestrial spheroid. Geodesy can therefore weigh them from afar, so to speak, and tell us of their distribution. Thus will it make us really see those regions which Jules Verne only showed us in imagination."

"This is not an empty illusion. M. Faye, comparing all the measurements, has reached a result well calculated to surprise us. Under the oceans, in the depths, are rocks of very great density; under the continents, on the contrary, are empty spaces."

"New observations will modify perhaps the details of these conclusions."

"In any case, our venerated dean has shown us where to search and what the geodesist may teach the geologist, desirous of knowing the interior constitution of the earth, and even the thinker wishing to sepculate upon the past and the origin of this planet."

From this extract it will be seen that the most eminent French authorities recognize the conclusions first formulated by Pratt over half a century ago. It only remains to consider the application of Pratt's theorem to the Himalayas and the plateau of Tibet.

If, as Pratt says, "the density of the crust beneath the mountains must be less than that below the plains, and still less than that below the ocean bed," it is very difficult to see how this could have come about except by the greater uplift of the mountains, by the injection of more light material beneath, while a less amount of such material has been injected under the plains, and scarcely any has remained under the ocean bed, because it tends to work out by the path of least resistance. This is the only explanation which satisfies the observed phenomena, and conforms to the known fact that the mountains and plateaus are uplifted by the expulsion of matter from beneath the sea, in world-shaking earthquakes. Thus the

known facts of geodesy as respects the Himalayas are fully explained. And the explanation rests on principles established by a variety of mutually confirmatory observations.

7. Defects in the Doctrine of Isostacy as Commonly Stated.

The doctrine of isostacy as commonly stated is vitiated by a serious if not fatal error; and it is necessary to overcome this defect if the doctrine is to hold its place in modern thought. In *Science* of February 10, 1911, Professor J. F. Hayford presents a paper based on the valuable data he obtained in the work of the U. S. Coast and Geodetic Survey, deduced from 765 series of astronomical observations at 89 stations in the United States. The causes assigned, however, are so inadequate that it seems worth while to point out the defects in his reasoning, which is as follows:

"Columns *A* and *B* have been assumed to contain equal masses. There is complete isostatic compensation. The pressures at the bases of the two columns are equal, and at any less depth, *X*, the pressure is greater in *A* than in *B*. Now assume that in the normal course of events a large amount of material is being eroded from the high surface of column *A* and deposited on the low surface of column *B*. After this erosion has been in progress

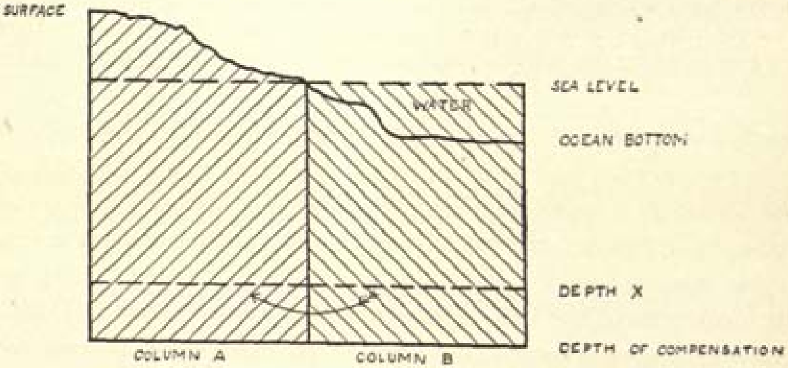


Fig. 1

for some time the isostatic compensation will no longer be perfect. The pressure at the base of *B* will be greater than at the base of *A*. The pressure very near the top of *B* will still be less than at the same level in *A* so long as the top of *A* remains higher than the top of *B*. There will be some intermediate level at which the pressure in the two columns is the same.

Call this level of temporary equality of pressure in the two columns the neutral level. As the process of erosion and deposition progresses the neutral level will gradually progress upward from its original position at the base of the columns. Eventually if no interchange of mass took place between the columns except at the surface, and no vertical displacement occurred in either column, the neutral level would reach the surface when the process of erosion and deposition became complete and the upper surfaces of the two columns were at the same level. During the process of erosion and deposition the excess of pressure in *A* at any level above the neutral level will continually decrease. Similarly, at any level below the neutral level the excess of pressure in *B* will continually increase as the erosion progresses and the neutral level will rise. Thus there will be established a continually increasing tendency for the material below the neutral level in *B* to be squeezed over into *A*. If the stresses tending to produce this undertow from the lower part of *B* to *A* become greater than the material can stand, the flow will take place as indicated by the arrow in the figure. If the material flows without change of volume, as if it were incompressible, the upper part of *A* and its surface will be raised, the upper part of *B* and its surface will be lowered, the neutral level will sink and an approximation to the original conditions with complete isostatic compensation will be reestablished."

"This is the general case of isostatic readjustment by the action of gravitation alone. Gravitation tends to produce a deep undertow from the regions where deposition is taking place to the regions where erosion is in progress, in the direction opposite to that of the surface transfer of material."

"Let us suppose that the isostatic compensation at a given stage in the earth's history is practically complete for a continent, that the process of erosion from the greater part of the continent and deposition around its margins is in progress, and that the process of readjustment by a deep undertow is in progress."

The fatal defect in this reasoning consists in the fact that it begs the question, and does not in any way explain the elevation of the margin of a continent, but only how it may maintain its present form by a process of readjustment. This is like a river rising higher than its source, or a man trying to lift himself by pulling on his bootstraps, or the logician reasoning in a circle. For in order to explain the development of the inequalities of the earth's crust, we must not only explain the adjustment and balancing between adjacent parts, but also *how the original uplift came about,* to give the observed contrast in surface levels.

Now on the premises used by Hayford, it is possible to explain how a given inequality of surface levels, when once existing, *can*

be maintained; but it is not possible to account for the *origin of the inequalities of level. Isostacy as thus depicted is not an active creative agency, but simply a negative process for maintaining existing inequalities.* Under the doctrine as above stated, the height of a mountain or plateau could never increase, for that would require the exertion of positive elevating forces, not mere balancing for maintaining inequalities of levels already existing.

Accordingly, this formulation of the doctrine of isostacy is defective, and inadequate to account for the phenomena of the earth's crust.

The true doctrine should include not only the *balancing process* described by Hayford, but also those *elevating forces directed from the sea,* by which the mountains are elevated as narrow walls about the borders of continents, on the great plateaus which spread out as wider embankments beneath them. Without these positive uplifting forces, no continent could ever have a mountainous border thrown up about it.

No doubt the elevation is produced under approximately isostatic conditions. Mountains can be forced up only to a certain height, the transfer of lighter material under the higher parts thus giving nearly equal mass in all equal prisms drawn to the center of the earth. The path of least resistance is towards regions of elevation, and the underlying material expands as the surface level is forced up. If this were not so the greater weight under the elevated region would cause it to subside to the common level. In this way, and in this way only, can progressive elevation be produced.

The weakness of the old method of reasoning is further illustrated by Hayford's remarks:

"Under a region of deposition two effects of opposite sign tend to occur. The effect of increased pressure tends to produce chemical changes accompanied by decrease of volume and so to produce a sinking of the surface. The blanket of deposited material tends to raise the temperature in each part of the material covered, to increase the volume of this material, and thereby to raise the surface. The temperature effect may serve in time to arrest the subsidence caused by increased pressure or even to raise the surface and change the region of deposition into one of erosion."

"The changes of temperature just described are due directly to erosion

and deposition. If as an effect of erosion and deposition an undertow is started tending to reëstablish the isostatic condition, this undertow, a flow of material presumably solid, necessarily develops considerable heat by internal friction. The increase of temperature so produced tends to cause an increase of volume. It may favor new chemical changes, including changes from the solid to the liquid state, which may be accompanied by a change of volume. The undertow tends to be strongest not under the region of rapid deposition, but under the comparatively neutral region between the two in which neither erosion nor deposition is much in excess of the other, see Fig. 2. Hence the undertow by increasing the temperature and causing a change of density may be directly effective in changing the elevation of the neutral region between two regions of deposition and erosion."

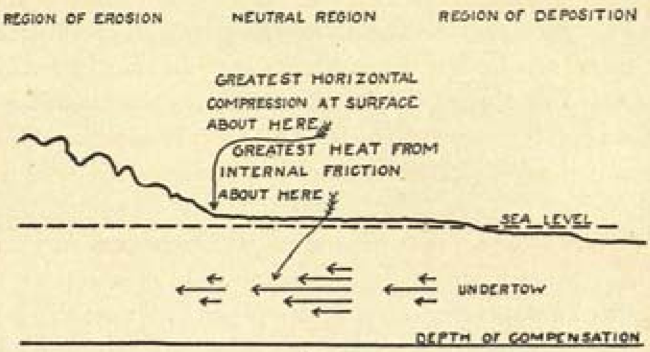


FIG. 2

"Horizontal compressive stresses in the material near the surface above the undertow are necessarily caused by the undertow. For the undertow necessarily tends to carry the surface along with it and so pushes this surface material against that in the region of erosion, see Fig. 2. These stresses tend to produce a crumpling, crushing and bending of the surface strata accompanied by increase of elevation of the surface. The increase of elevation of the surface so produced will tend to be greatest in the neutral region or near the edge of the region of erosion, not under the region of rapid erosion nor under the region of rapid deposition."

The criticism against this reasoning is the same as that used above—namely, it will explain only balancing, but not the uplifting of great mountain walls along the sea coast. Nothing but the transfer of lava from beneath the sea, and the expansion of it under the mountains will explain the observed mountain walls along the borders of continents; and this requires positive forces of elevation, not mere negative processes. The advocates of isostasy, as

heretofore taught, have left that doctrine with such a serious defect that this correction is necessary to give it a rational basis.

8. The Uplifting of the Himalayas, Arrakan and Afghanistan Ranges Explains the Great Asiatic Earthquake belt. Confirmation of Colonel Burrard's impressions that the Himalayas have been Pushed Northward, but not by a Change in the Rotation Period of the Earth.

We have seen that the region now occupied by the rivers Indus and Ganges was formerly a sea valley; and that after the Himalayas were elevated to a great height, the valley itself was slowly raised above the ocean.

If proof is asked that the valleys of the Indus and Ganges were formerly below the sea, it is furnished by the well-established fact that such valleys as the San Joaquin and Sacramento in California were below the sea when the Sierras were being elevated. What has happened in California has also happened in India; and the same process of elevation will eventually give a fertile habitable valley in the belt just south of the Aleutian Islands now covered by a sea nearly five miles deep.

This proof that the valleys of the Indus and Ganges were once several miles beneath the sea level is absolute. For it is definitely known how the mountain ranges and adjacent valleys are crumpled, and finally raised above the sea. And what has happened for mountain ranges in general, has happened also for the Himalayas and the valleys adjacent thereto.

In order to round out the view here traced, it only remains to add that the Arrakan coast of Father India contains two chief mountain chains, one of which is the backbone of the Malay Peninsula; and the other is the range terminating at Cape Negrais, but continuing under the sea in a string of islands, and reappearing further south as Sumatra and Java. The Andaman islands and several volcanoes in the sea appear between Cape Negrais and Sumatra. And both Java and Sumatra are noted for their terrific

volcanic violence. This volcanic chain is analogous to that of the Aleutian Islands, except that the middle part is submerged, and the two ends raised above the waves.

The line of thought here developed enables us to understand the volcanic activities of Farther India, and also the terrible belt of earthquakes in Assam and the adjacent regions south of the Himalayas. Part of the ancient sea valley is above the water as low land, and part still in the ocean, and covered by the sea to a considerable depth.

West of India, we have the complicated mountain ranges and earthquake belts of Afghanistan and Persia. It would be difficult if not impossible to understand the phenomena they present if studied alone; but if studied in connection with the developments of India and Farther India above discussed, it is easy to see that Afghanistan and Persia were built up in like manner, and at no very distant epoch were beneath the sea.

In his article on the "Himalayas," Encyclopedia Britannica, 9th edition, the late General Strachey has strongly emphasized the view that the mountains and table lands of Afghanistan and Persia are intelligible only in connection with those of India.

> "It is after the middle Tertiary epoch that the principal elevation of these mountains took place, and about the same time also took place the movements which raised the tablelands of Afghanistan and Persia, and gave southern Asia its existing outlines."

He also points out the fact that at no very distant geological epoch the ocean extended from the Arabian Sea through the Persian Gulf to the Caspian and Mediterranean. The continuation of the earthquake belt through this region of Western Asia is therefore quite intelligible, and the existence of active volcanoes near the Caspian a survival of present and former relations to the ocean.

The annual rainfall south of the Himalayas amounts to about 36 feet, and this is so enormous as to be almost as effective as a shallow sea in keeping alive earthquake processes.

It is established by observation, for example, that the very

active volcano Sangai, in the terrible rain belt at the head of the Amazon, in Ecuador, has its activity about doubled during the worst period of the rainy season, owing to the effects of surface water. If in South America the volcanic forces can be visibly augmented by copious surface water, it is easy to understand that the terrible rains of India may also operate to keep alive the earthquake processes almost as well as an overlying sea.

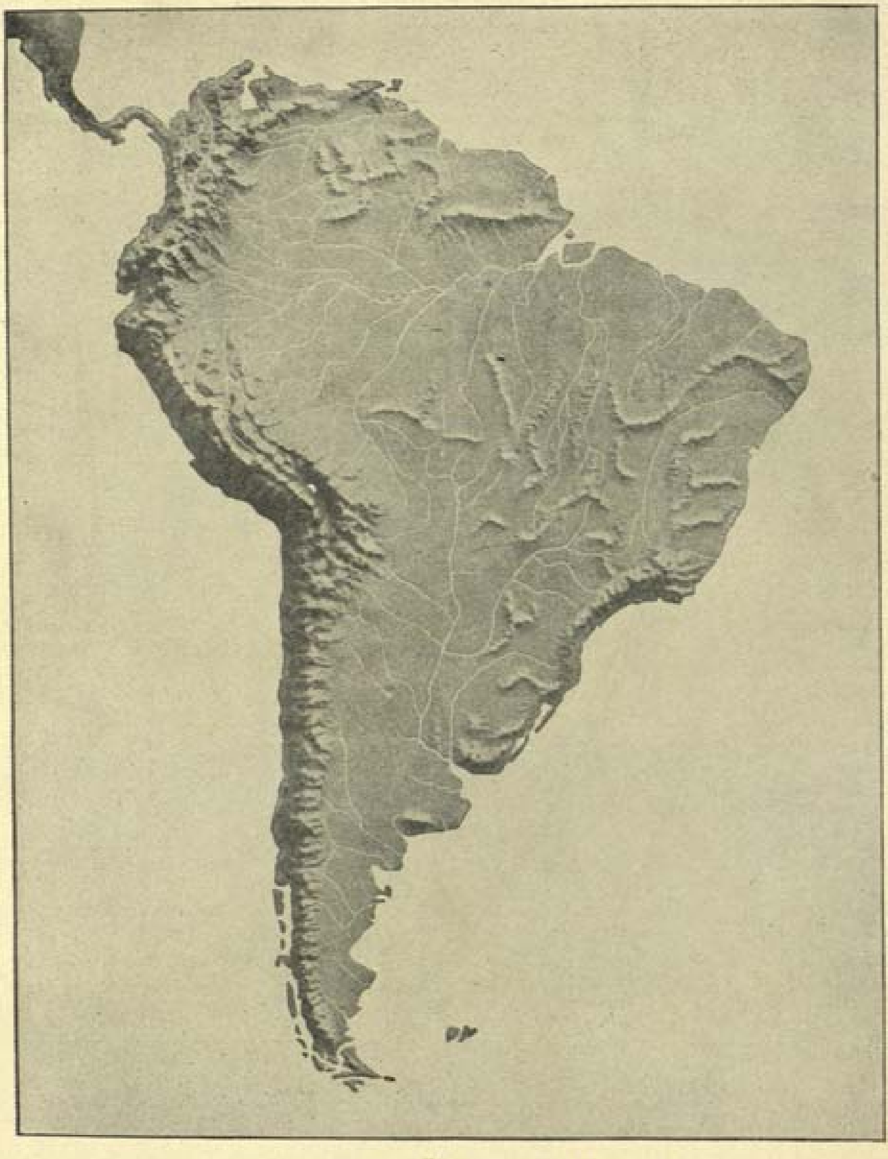
The earthquake belt south of the Himalayas is thus perfectly explained. And the extension of this line of disturbance through to the Caspian presents no difficulty, when account is taken of the recent situation of the sea over a large part of this region of western Asia.

In conclusion it only remains to add that Colonel Burrard's argument, cited in Section 1 above, *that the Himalayas resulted from the pushing of a great mass of matter northward, undoubtedly is correct.* This fact appears to be as well established as the rising and setting of the sun, and further discussion of the subject is superfluous.

The cause of this northward movement is also fully established, but it is not that imagined by Colonel Burrard. In the *Observatory* for May and June, 1912, will be found a discussion by Colonel Burrard of considerable interest, but founded on the premises that the earth's speed of rotation is variable and has undergone considerable changes within the period covered by geological history.

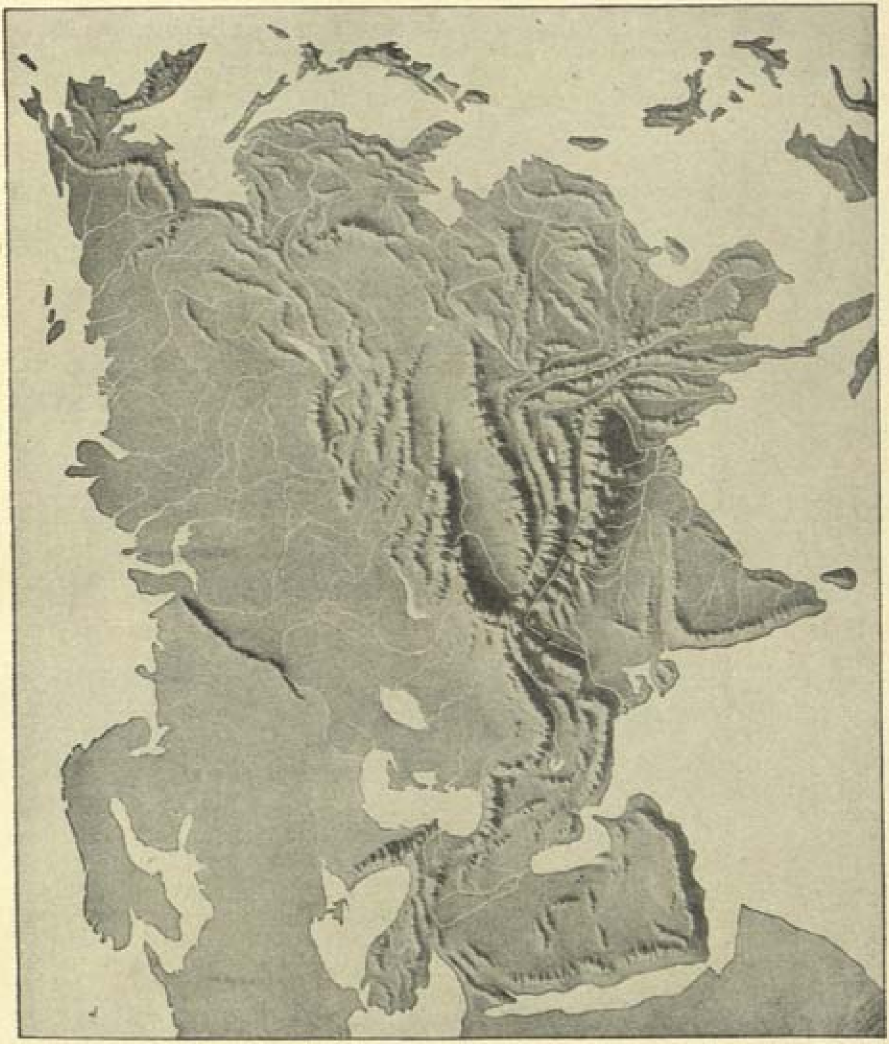
The writer's "Researches on the Evolution of the Stellar Systems," Vol. II., 1910, show that the views formerly held by Lord Kelvin and Sir George Darwin are now quite inadmissible; and that the earth's rotation has not changed sensibly since the earliest geological time. Thus Colonel Burrard's premise that the retardation of the earth's rotation might cause a flow of matter towards the poles is wholly inadmissible.

Besides, there are other means of showing that such was not the origin of the Himalayas. *These great mountains of India, for example, should no more be due to a change in the earth's rotation, than should the Andes, which run almost exactly north and south, and by their course along the meridian, exclude an explanation founded on a change in the speed of the earth's rotation.*



RELIEF MAP OF SOUTH AMERICA.

From Frye's *Complete Geography*, by permission of Ginn & Co., Publishers. Illustrating the New Theory that the Mountains were formed by the oceans, and thus run parallel to the Sea Coast, as in the typical case of the Andes. It was this vast wall along the Western sea-board of South America and the earthquakes afflicting that region that led to the discovery of the cause of Earthquakes and Mountain Formation in 1906. The foundations of the New Science of Geogony were thus laid by the writer, soon after the great earthquakes which devastated San Francisco and Valparaiso.

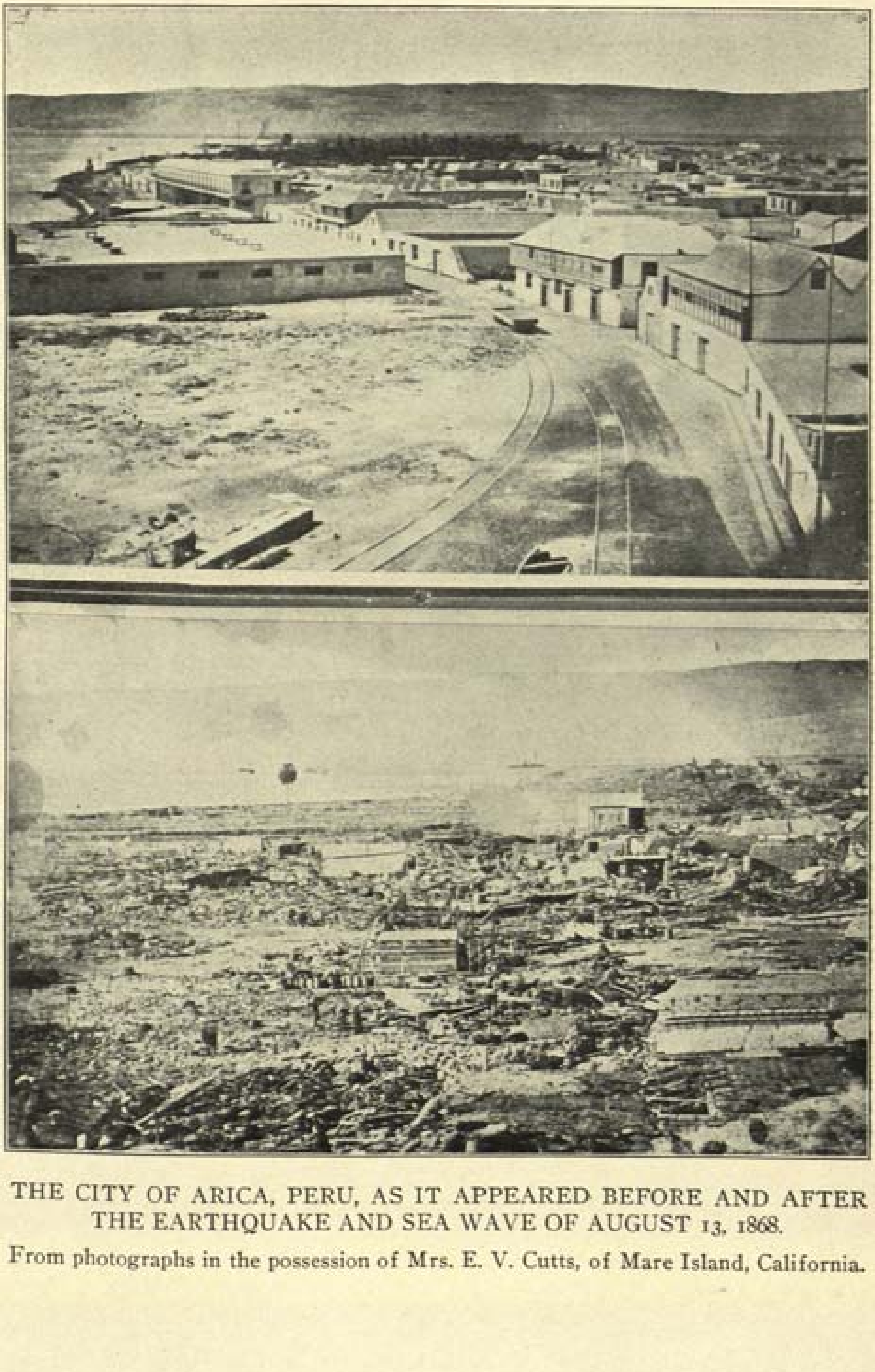


RELIEF MAP OF ASIA.

From Frye's *Complete Geography,* by permission of Ginn & Co., Publishers. Showing the development of the Himalayas and Plateau of Tibet by the Indian Ocean on the South, and other ranges of Mountains by the Pacific, along the Eastern shores of the Continent. Before India was raised from the ocean, the sea coast ran parallel to the Himalayas, as in the case of the Andes in South America.

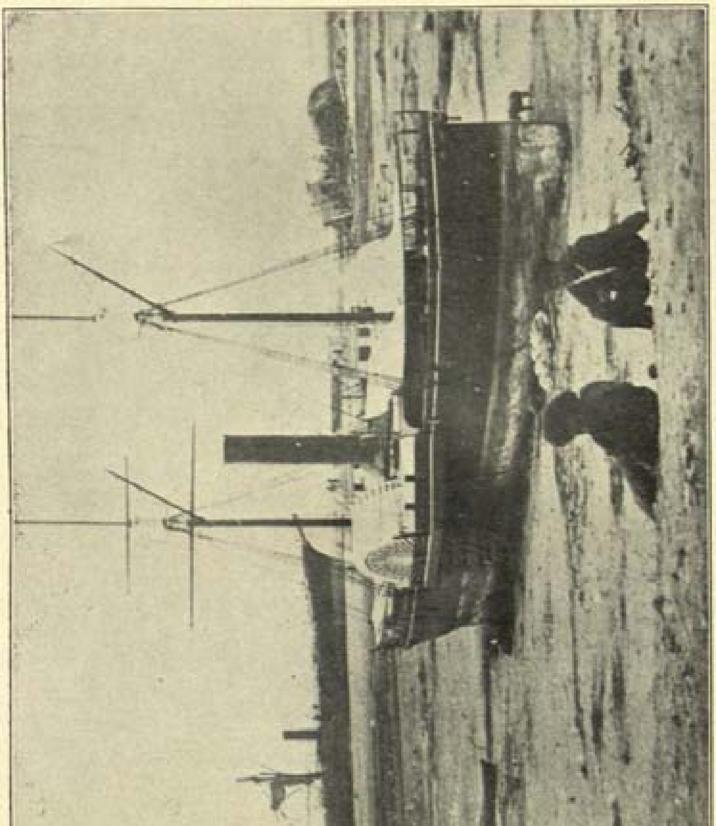
MAP OF INDIA.

From the *Encyclopedia Britannica,* ninth edition, showing the location of the Himalayas and Plateau of Tibet in relation to the neighboring parts of India.



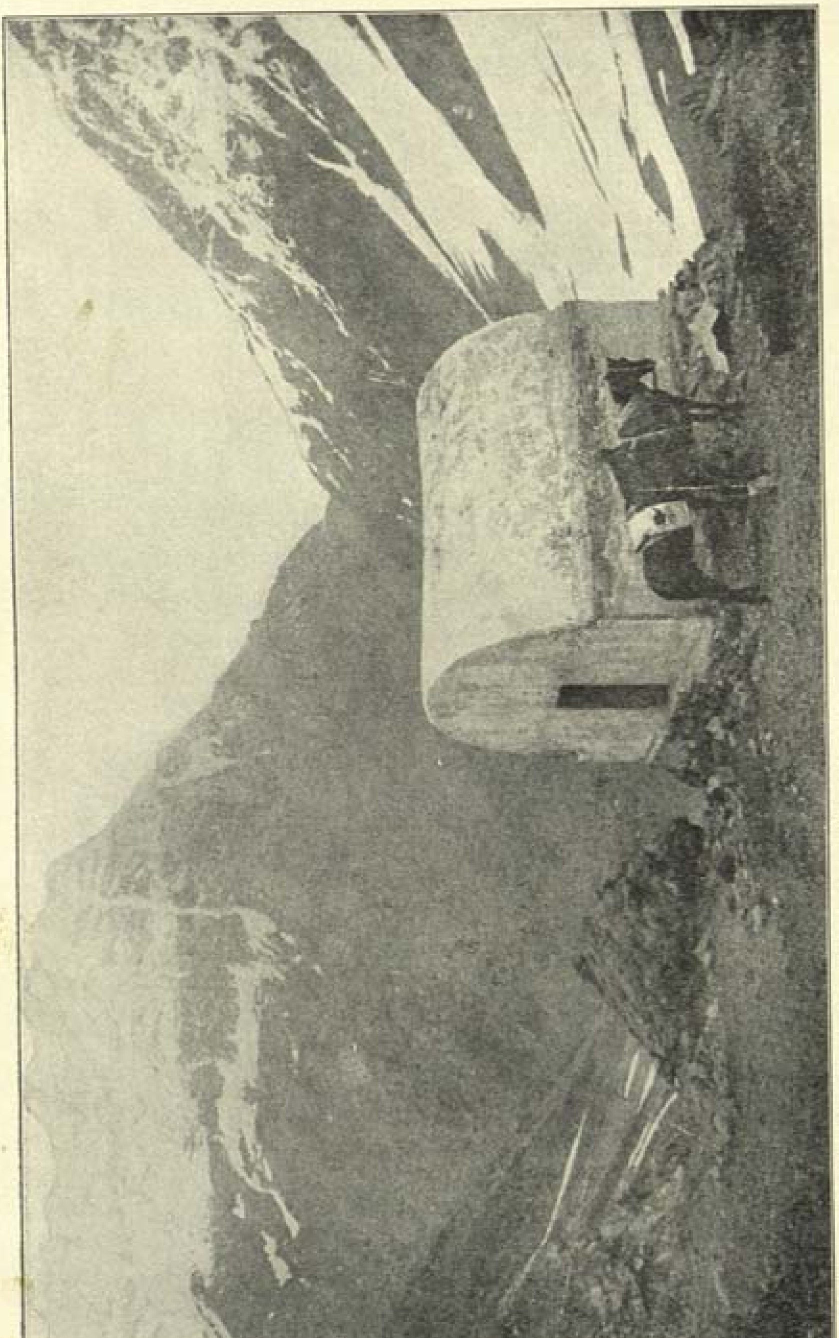
THE CITY OF ARICA, PERU, AS IT APPEARED BEFORE AND AFTER THE EARTHQUAKE AND SEA WAVE OF AUGUST 13, 1868.

From photographs in the possession of Mrs. E. V. Cutts, of Mare Island, California.



THE SHIP IN THE FOREGROUND IS THE U. S. S. WATEREE.

It was washed half a mile inland by the great sea wave at Arica, Peru, August 13, 1868.
From a photograph in the possession of Mrs. E. V. Cutts, Mare Island.



PASSAGE IN THE ANDES, BETWEEN CHILE AND ARGENTINA.

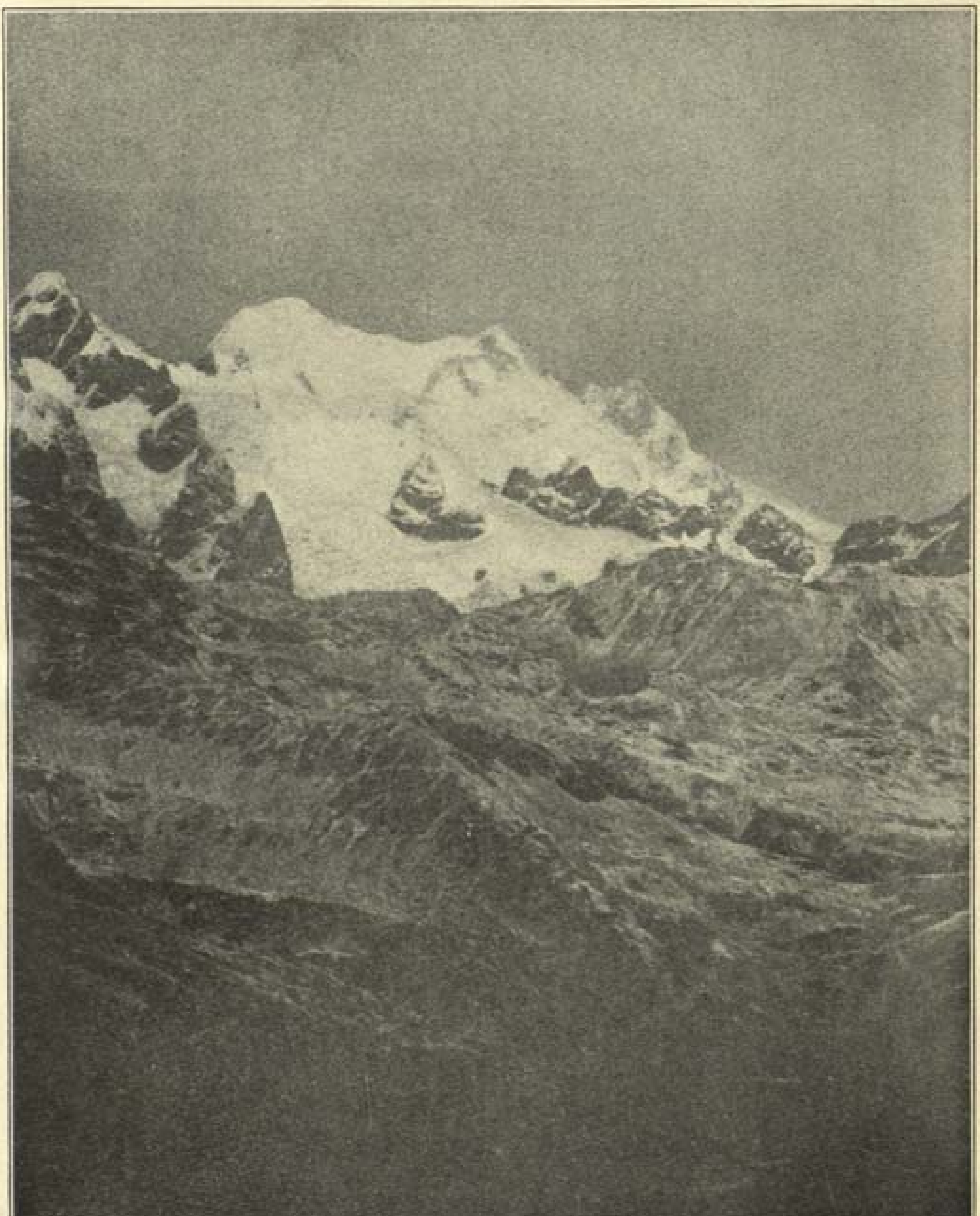
Showing a Stone House built for the shelter of travelers, against violent storms which are frequent at these great altitudes.

Photograph by Harriet Chalmers Adams, *National Geographical Magazine* for May, 1910.

MT. HUASCARAN, IN CENTRAL PERU, ALTITUDE ABOUT 24,000 FEET.
Photograph and copyright by Miss Anna S. Peck, *National Geographical Magazine*, for June, 1909. Used by special permission of Miss Peck.

MT. ACONCAGUA, IN CENTRAL CHILE.
The highest Volcano in the world, and long considered the summit of the Andes. Altitude, 22,800 feet.

TYPICAL VIEW OF THE ANDES, NEAR ACONCAGUA, CENTRAL CHILE.

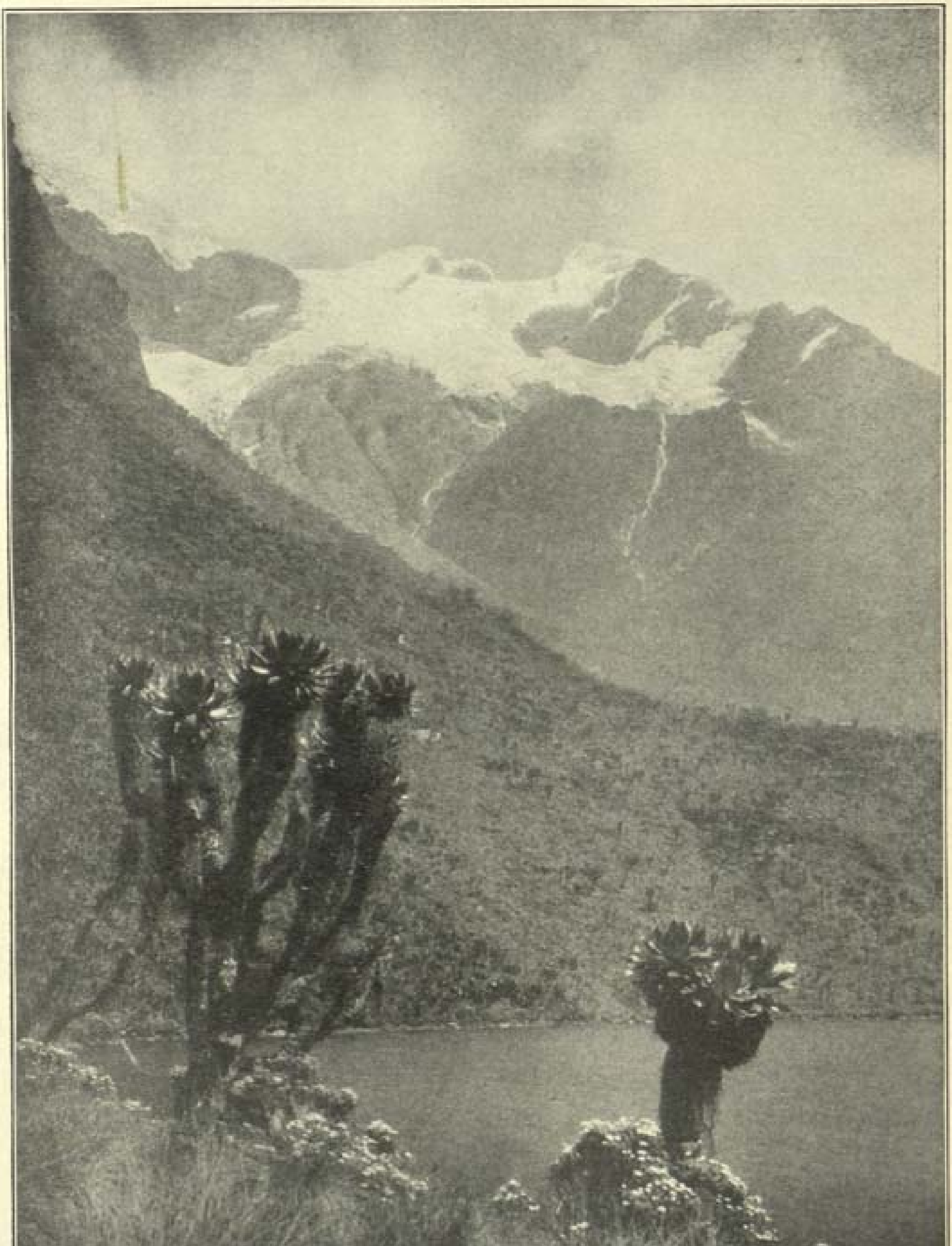


MT. EVEREST, THE HIGHEST PEAK OF THE HIMALAYAS AND OF THE WORLD.

Altitude 29,002 feet above sea level. Photograph by Vittorio Sella, from Chunjerma Pass (Nepal), 80 miles distant, *National Geographical Magazine* for June, 1909.

MT. KENGCHENJUNGA, NEAR MT. EVEREST, AND SECOND HIGHEST PEAK OF THE HIMALAYAS.

Altitude, 28,150 feet. Photograph by Vittorio Sella, *National Geographical Magazine* for June, 1909.



THE RUWENZORI

In Equatorial East Africa rising to an altitude of 18,600 feet. This snow capped range in the hottest part of Africa was explored by the Duke of the Abbruzzi in 1906. Photograph by Vittorio Sella, from the south, *National Geographical Magazine*, for June, 1909.

VIEW OF THE ALPS FROM THE SUMMIT OF MATTERHORN.

Showing the terrible upheavals involved in the uplift of the Alps. Photograph by G. P. Abraham, *National Geographical Magazine* for June, 1909.

And as the Andes are well known to have been formed by the sea, in the way we have described, it is certain that the same cause uplifted the Himalayas and the plateau of Tibet.

From these considerations it will be seen that the modern sciences of geogony and cosmogony are closely related, and that neither can be perfectly developed without the aid of the other. Just as it is impossible to develop a satisfactory theory of the formation of the earth without data drawn from the modern science of cosmogony; so also cosmogony itself has been much improved by a science of geogony which gives a correct theory of terrestrial mountain formation. For that has aided in establishing the origin of the lunar craters, and the early growth of the earth itself by impact. The existing ranges of mountains have been subsequently formed by the sea and thus made parallel to the coasts. On the other hand, without the theory that the mountains generally are formed by the ocean, which is so clearly established for the typical range of the Andes, running exactly north and south, our ideas of the origin of the Himalayas might have remained obscure for ages.

It is scarcely necessary to point out that these results illustrate somewhat impressively the value of a comprehensive vision in the study of the sciences. Without this power for comparing together the most remote objects there can be no progress in discovery of the highest order.

Starlight on Loutre,
Montgomery City,
Missouri,
March 27, 1913.

FACTORS IN THE EXCHANGE VALUE OF METEORITES.[1]

By WARREN M. FOOTE.

(*Received April 25, 1913*)

Historical.—For many years an acceptable standard of meteorite values has been sought by students and investigators in this branch of geology, as well as by those museums or individuals who aim to complete the great collections. While the supply of one locality or fall is often known to the fraction of a gram, its institutional owner's reluctance to exchange may not be measured by any known formula. It is then most natural that negotiations frequently pro-

[1] Since values are not settled by individual, but by collective opinion, an outline of this article was submitted to several active exchangers. The curator of one of the two greatest meteorite collections warmly commends the effort to determine exchange values from new viewpoints. He expresses the belief that museums in general will utilize the work, and will welcome the elaboration of any detailed system which affords a standard of value for meteorite exchanges.

Professor E. A. Wülfing writes:

"Your article on the factors which determine the exchange value of meteorites interested me very much. . . . In my consideration of the matter in 1897, I did not think primarily of market prices, but of exchanges between the large museum stocks, which I thought was not wholly impossible. The purchase price was only considered by me in so far as it influenced the choice between the formulæ W_1, W_2 and W_3. Your second factor, 'weight of specimen offered,' could not influence me, since there seemed to be much too little of what was offered in 1897, in comparison with the large museum-masses to be dislodged. . . . But these were all factors which it was impossible to consider in 1897; likewise the 'area of slice' had to be set aside, otherwise the problem of clearing away the endless confusion in the price question would have grown still more insoluble.

"I would say therefore, that in quite properly criticizing the formula, . . . the conditions which produced it, and which only could have produced it, should be considered. . . . I believe that you have undertaken this [extension of the formula] in the right way and I wish to express the hope that you may succeed in further distributing meteorite masses and thereby advance their study."

long into failure during the years which are required for exchangers to get together. Apart from the few who devote much time to meteorites, are the many to whom they have but an incidental and minor interest, and who have little idea of values other than those given by the owner. Hence the occasional as well as the regular collector may find worth while a brief examination of the subject. We may first exclude local values, since they are usually determined by agreement between finder and buyer.

The first to attempt any systematic enlightenment in this field was Dr. Otto Buchner. In 1863 appeared his volume on meteorites in collections,[2] wherein he noted 230 different localities.

Thirty-four years after Buchner's publication, Professor E. A. Wülfing, an eminent authority, wrote: "The present interest in meteorites on the part of many, could be increased by a wider distribution of material. Believing that this is attainable through active exchanging, and further because I see an aid to this end in a determination of the relative value of meteorites, even if only approximately, I shall endeavor to establish their exchange values." Accordingly, in 1893 he wrote to all owners or curators of meteorite collections, asking them to report the weight of each meteoritic fall or locality in their possession. Then followed a long and voluminous correspondence which, with the arduous tabulation of the data secured and the development of his formula, delayed for nearly four years the publication of his exhaustive treatise[3] of some 500 pages. The major part of this work consists of a list of all known meteorites, giving, for each, the full locality, symbol, date of fall or find, bibliography, original weight, present known weight, and finally, a list of owners with the weight in grams of their holdings. In the two concluding chapters is elaborated a theory of values. He finds but three important factors which enter into the value of each meteorite:

1. The Present Known Weight.—This, Wülfing states, is incomplete in many cases, because of his failure to reach some owners and to secure full data from others. Where the original weight is un-

[2] "Die Meteoriten in Sammlungen, ihre Gewichte, mineralogische und chemische Beschaffenheit."

[3] "Die Meteoriten in Sammlungen und ihre Literatur," Tübingen, 1897.

accountably reduced, some of the shortage is considered in the exchange value given to such falls.

2. The Group Weight.—A modification of the admittedly imperfect Rose-Tschermak-Brezina group classification, is used, showing each group weight.

3. The Number of Owners.—Wülfing acknowledges the unreliability of this factor, in that some owners have not enough to part with any and should therefore not be included. However he includes all owners as of equal importance in his formula for finding the value of a fall, arguing that when divided among many holders, it is less desirable in other eyes.

The following variable factors, which he excludes, are then referred to as not being computable or as of insufficient weight to be utilized in working out the formula: (4) Material which may be found in the future and thus raise certain group-weights, especially of the rarer groups, when new individuals of such are found, (5) the original cost of collecting specimens, (6) state of preservation, (7) historical interest, (8) if seen to fall, the meteorite is valued higher, especially in the case of nine irons so distinguished. The wisdom of doubling his valuation of these nine falls, or making even a greater increase, is left by Wülfing as an open question. Concerning the stones, he states that there is generally no difference in value between the few not seen to fall and those seen to fall.

The author here begins a mathematical inquiry into the relative value of the three factors chosen; Group Weight (G), Present Known Weight (N), and the Number of Owners (B). Following a long analysis with numerous allowances and exceptions, he establishes the exchange value (W) in the formula,

$$W = \frac{1}{\sqrt[3]{GNB}}$$

Four tables follow for estimating the value of new meteorites: the first is for meteorites having from 1 to 3 owners; the second 4 to 8 owners; the third 9 to 20; the fourth table being for those of 21 or more owners. The group weight is given vertically and the locality weight horizontally. At the intersection of these lines is a numeral indicating the exchange value per gram, taking the value of Canyon

Diablo as unity. It is thus not a money value, but an exchange value index.

In the next chapter is a group classification of all meteorites known in 1897, giving figures under *U* (original weight), *N*, *B* and *W* for each fall. In the determination of *U* and *N* and in their discrepancies, many uncertainties arise, and on this account two values are given for some falls and other values are omitted altogether. In some of his value-pairs Wülfing indicates the less probable of the two within parentheses. Again where both values are doubtful, they are enclosed in brackets.

In 1899, the late Professor E. Cohen, author of many important scientific studies of meteorites, published a table[4] collating the Wülfing exchange values with the trade prices of eight dealers. For each fall, he showed in one column the lowest dealer's price in pfennigs, then the highest, and in a third column the medium or average of all prices. The Wülfing exchange values ($\times 13$) he gave in a fourth column. This table afforded a basis for comparing the theoretical exchange value with the actual market price of each fall.

Professor Cohen called attention to the fact that previously no account had been taken of the area of a slice, maintaining that this feature should receive full consideration in estimating the value. Examining the tabulation, he pointed out that about one third of the falls compared, showed large variations between the medium trade price and the Wülfing exchange value. Most of the relatively low figures of Wülfing he ascribed to the fact that although the masses are very large, they are securely held against partition by sale or exhange. On the other hand, many of Wülfing's relatively high figures are due to the fact that they belong to the rarer groups, which, according to Wülfing's critic, come on the market only by chance, and with no fixed value. Finally Cohen stated that it is not the number of owners which affects the value of a particular fall, but the number of owners who are able to part with some of their holding, a collector of pieces under 15 to 30 grams being

[4] "Über den Wülfing'schen Tauschwerth der Meteoriten im Vergleich mit den Handelspreisen," *Mitth. aus dem naturwiss. Ver. für Neu-Vorpommern u. Rügen*, 1899, XXXI., pp. 50–62, Greifswald.

negligible in an estimate of available exchange material. He concluded his review with a conditional acceptance of the exchange basis established by Wülfing, and welcomed his guidance among those final personal factors which in the past have rendered meteorite exchanging so difficult a process.

In 1904 the late Professor Henry A. Ward, the greatest traveling collector of meteorites, made a new collation[5] of seven dealers' prices, contrasting his results with those of Cohen. Professor Ward included the prices paid at a large meteorite auction, as well as two records of many sales, but excluded all abnormal figures. He was the first to fully emphasize the fact that a large specimen is worth far less per gram than a small one of the same fall. However, he greatly overestimated this variation in saying, in effect, that an increase of sixteen-fold in weight deserved a decrease to one eighth the gram price. This would make a 16-pound piece worth only twice as much as a 1-pound piece of the same fall.

Present Factors.—In using the Ward Collation, the writer, in common with most exchangers, found it of great value, but as often lacking because of the numerous meteorites commercially quoted during the intervening eight years. In making a 1912 collation for personal use, it seemed worth while to check it carefully throughout and publish with certain observations.

The following arrangement of the main elements of meteorite values, attempts only to roughly indicate the order of their importance. The first factor may make a difference of several hundred-fold in the gram price, the second usually five to ten-fold, and rarely much more. The remaining factors generally involve lesser variations.

Essential Factors.

1. Present known weight.
2. Weight of specimen offered.
3. Number of owners.
4. Group weight.
5. Observation of fall.

[5] "Values of Meteorites: Relative and Individual," *The Mineral Collector*, Vol. XI., No. 7, pp. 97–115, New York.

Occasional Factors.

6. Area of slice offered.
7. Phenomenal variation between individual specimens.
8. Distinctness of structure.
9. Missing portions.
10. Historical interest.

1. *Present Known Weight.*—Wülfing distinguishes between the original weight and the present known weight among recorded owners. After the original weight is announced, usually the only important loss is by sawing, etc.; hence the portions held by unknown owners should not be ignored. In general the present weight may be approximated by subtracting from the original weight, a loss of 10 per cent. to 30 per cent., according to the extent and manner of division.

Evidently we have here supply versus demand in its simplest aspect. Thus, Canyon Diablo and Toluca are at one end of the list, with many tons distributed, and respectively offered at 3 cents and 4 cents per gram, or only double the price of silver. Omitting Adalia and one or two others of which only a few grams are known, we may take as typical of the most costly meteorites, Angra dos Reis, Barea and Epinal, with an average known weight of 1,000 grams. These bring over $7.00 per gram, or ten times their weight in gold.

2. *Weight of Specimen Offered.*—This variation is based on the high costs of sawing irons, as well as on the consequent loss of one tenth to three tenths of their mass; and finally on the expensive distribution of all kinds of meteorites to the most limited, yet widely scattered, of markets. While this principle is generally recognized in practice, the fact that it is second only in importance to the weight of the fall, is frequently overlooked. Although excluded by Wülfing, if allowance is not made for this element, his system often becomes misleading in individual transactions. Its relative importance is shown by many sales. Thus, Canyon Diablo, of which fifteen to twenty tons have been distributed, brings in 100 gram pieces 3 cents per gram, and in 100 kilogram pieces three tenths cent per gram, or $3.00 per kilogram. That is, a thousand fold

increase in weight means a reduction to one tenth of the per gram price. At rare intervals greater extremes of this price variation are shown by wholly abnormal and unstable quotations.

In the case of iron localities affording a few hundred to a few thousand kilos, a ratio of price variation of about 8 : 1 will be typical where the weight variation is 1 : 1,000. This is roughly illustrated in the table below by the recently found Amalia, a fall identical with the original Mukerop.

Ordinary Prices.		Exceptional Prices.	
Highest.	33 Per Cent. Decrease.	50 Per Cent. Further Decrease.	60 Per Cent. Final Decrease.
Very thin slices of about 30 grams (0.03 kilo)	Thin slices of about 300 grams (0.3 kilo)	Thick slices of about 3000 grams (3 kilos)	Very thick slices or end-pieces of about 30,000 grams (30 kilos)
6 cents per gram ($60.00 per kilo). Price, $1.80	4 cents per gram ($40.00 per kilo). Price, $12.00	2 cents per gram ($20.00 per kilo). Price, $60.00	0.8 cent per gram ($8.00 per kilo). Price, $240.00

One universal tendency is for the price variation to lessen directly with the decrease in total weight, so that in meteorites totaling less than 1,000 grams, the price variation may not exceed 3 : 2 in a weight variation of 1 : 10. There are two elements in price variations between 30 and 30,000 grams. The first element is difference in weight and the second is difference in thickness. If we eliminate the latter, there is less price variation. Thus an iron slice of 3,000 grams, measuring 20 × 20 × 1 cm. thick, is worth nearly as much per gram as a 30-gram piece measuring 2 × 2 × 1 cm. This is partly because the relative cost of sawing a large slice is more than for a small one. Stony meteorites have a smaller ratio of price variation, generally ranging below 4 : 1, in a weight variation of 1 : 1,000, because the costs of sawing are less than for irons. Further, single stones of over 20 kilos are somewhat rare and are in demand as complete individuals. It may be further noted that collectors differ as to whether aerolites are better sawed or broken. The latter method of division avoids waste of material and labor costs, and affords a broader fractured surface; at the same time it does not prevent polishing a small face if desired. In falls dis-

tinguished by an abundance of small complete individuals, their gram price is somewhat lower than that for slices, because of the sawing cost. Examples are Canyon Diablo, Toluca, Estherville, Mocs, Pultusk, Holbrook, etc.

3. *Number of Owners.*—As pointed out by Cohen, this, to a buyer, is secondary to the number of those who might part with some of their holdings. Omitting irons seen to fall and localities of which the original weight was much greater than the present recorded weight, the market values of the following are more than three times those of Wülfing: Barea, Bendego, Daniel's Kuil, Djati Pengilon, Elbogen, Emmitsburg, Epinal, Juncal, Krähenberg, La Caille, Molina, Nulles, Petropavlovsk, Red River, Tieschitz and Wold Cottage. For the preceding list, the average number of recorded owners is 21, but only one or rarely two owners of each fall have an excess over their own requirements. Wülfing's low price, based partly on the number of owners, is here in great measure explained. Nevertheless the disposer of a meteorite, in evaluating it, will consider the likely exchangers, lowering his price according to the number of those who already possess nearly as much as their probable requirement.

On the other hand some of the cheapest meteorites in the market are held at first by some one dealer whose policy is to sell at a figure which will dispose of his stock within a few years. In nearly all cases where a locality is so controlled, the price is lower than the Wülfing value, and far lower than if held by a large institution which has parted with little or none. The high exchange offers which the institution receives, even though uninvited, tend to elevate the trade price until their exchange policy loosens. Many of the highest ruling prices are largely due to such influences. Further on this is clearly shown in a comparative analysis of the Wülfing values and the trade prices collated by Cohen.

This factor of available weight, so dependent on personal inclination, is the most uncertain of the essential elements, the fall being almost unobtainable where it is preserved entire as municipal or church property. Between the extremes cited lie those meteorites held in public meteorite collections, where the policy is nearly

always against the preservation of a fall in its entirety. For the purpose of study, a broad slice or polished end piece is quite as valuable as a large mass of iron.

4. *Group Weight.*—Stony meteorites are classified in groups according to their petrographic structure and composition; irons according to their crystallization. Wülfing gives this second position among the factors of value. He calculates the total weight of each group, giving to individual falls a value influenced by the group weight.

5. *Observation of Fall.*—This factor is placed eighth and last by Wülfing. His final exclusion of such a factor constitutes another limitation of his formula, as may be seen by a comparison of actual selling prices with his theoretical values. Of about 300 known irons, only nine have been seen to fall. Comparing only these siderites seen to fall and listed by Wülfing, which have been retailed: Agram, Charlotte, Braunau, Rowton, Mazapil, we find that Wülfing's theoretical value averages for these five falls 55 cents per gram, whereas the last quoted selling prices averaged $4.71 per gram, showing that sellers have rated irons seen to fall at more than eight times the figures that Wülfing accords them.

Four siderolites seen to fall, Estherville, Lodran, Mincy and Veramin, which are collated by Cohen at an average of $3.06, are estimated by Wülfing at an average of $4.42. This comparison is quite inconclusive because of the uncertainty as to the location of a large portion of the original weight of Lodran. As Wülfing estimates it by the present recorded weight, its value is enormously inflated ($15.71), thus nullifying the results. Eliminating Lodran, the remaining three are averaged by Wülfing at $1.99 and by Cohen at $6.61, showing that siderolites seen to fall are estimated by Wülfing at less than one third their market value.

But when we examine the aerolites, we find that out of nearly 400 known stones, only about one twelfth have not been seen to fall. The following ten aerolites not seen to fall, are the only ones quoted by dealers and estimated by Wülfing: Goalpara, Tomhannock Creek, Waconda, Prairie Dog Creek, Long Island, Salt Lake City, McKinney, Bluff, Pipe Creek and Minas Geraes. The average of the

last quoted medium trade prices, is 75 cents, and their average Wülfing price is $2.20. Thus on stones not seen to fall, Wülfing estimates about three times the market value.

6. *Area of Slice.*—According to Cohen, a section of relatively large exhibition area is of more value per gram than a thicker piece of the same weight. Of two pieces of the same weight, the one having the larger exhibition surface will be chosen, as better illustrating the variation in structure, crystallization and included minerals, besides making a more impressive display. However, most 1912 catalogues show no apparent difference in the price per gram because of differences in thickness. While there is little advantage in a slice of iron 20 to 30 cm. broad being more than 1 cm. thick, some siderolites and aerolites require a greater thickness because of their friability. Quite apart from the relative desirability of two pieces of the same weight but of differing exhibition area, is the large item of cost, since a thin slice costs proportionately more per gram for sawing and wastage than a thick slice.

7. *Phenomenal Variation between Individual Specimens.*—Interesting differences between individual slices or masses of the same fall are often seen. In aerolites, one fragment or slice may (1) have much more crust than another; (2) it may show a slickensided surface; (3) primary and secondary crust formed before and after exploding; (4) radial lines of fusion flow on the front, with thicker overflow on back; (5) brecciation, etc. In irons, one slice may (1) rarely show hieroglyphic characters and often nodules of included iron compounds; (2) twinning; (3) a flowage of the usually straight Widmanstätten figures; (4) on the exterior deep pitting, or fluidal lines; (5) more commonly, marked octahedral cleavage. Such features increase the value of one piece over that of another of the same weight and fall which is less interestingly marked. An extreme case is Canyon Diablo, valued at 3 cents per gram. When showing diamonds (of no commercial value), the price has exceeded 30 cents per gram.

8. *Distinctness of Structure.*—Other things being equal, beautifully crystallized irons and stones of striking chondritic structure, are prized higher than those in which the crystallization is clouded or the structure quite indistinct.

9. *Missing Portions.*—This factor concerns very few meteorites, but where formerly unobtainable pieces are secured, they naturally cause a depreciation in the price. Such a drop is sometimes discounted where the ultimate availability of the missing portion is assured.

10. *Historical Interest.*—Comparatively few falls are affected in value by this element. Where a meteorite has fallen near a town and has been preserved as an object of civic pride for many years, as in the case of Krähenberg, Elbogen and Ensisheim, its value is greatly enhanced, since it is practically unobtainable. Again, when it has been worshiped or venerated by primitive or even civilized peoples, as in the case of Wichita, Durala, Kesen and many others, its value is slightly increased. Finally, the one or two prehistoric meteorites (Casas Grandes, Anderson, etc.) have a somewhat higher value because of their ethnological interest.

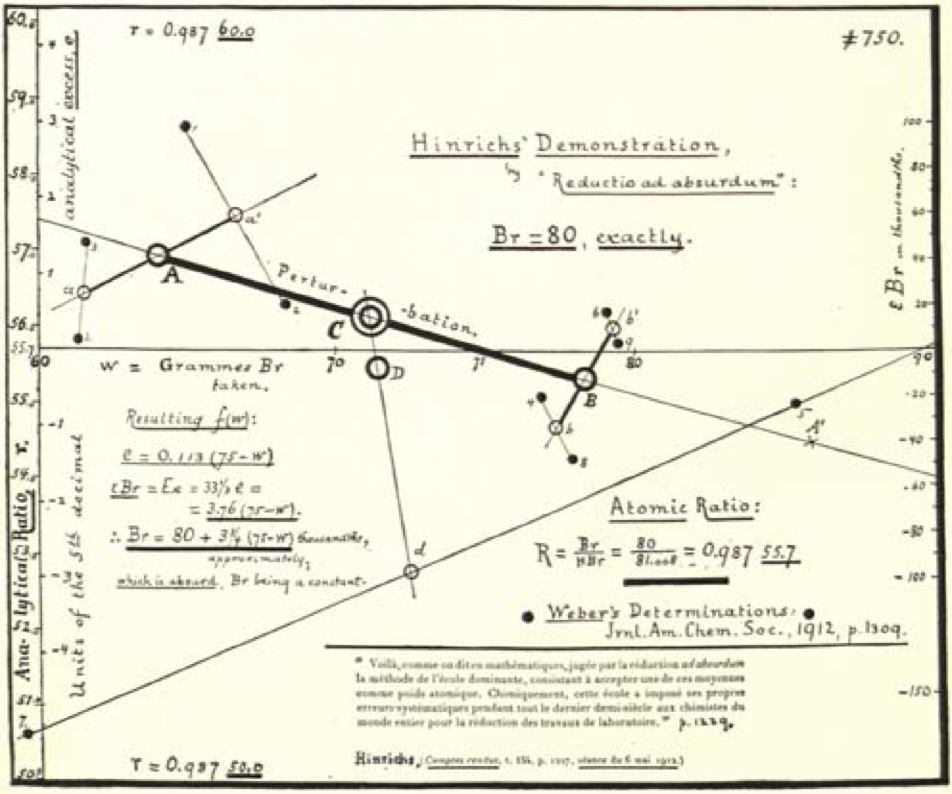
The 1912 Collation.—Leaving the general discussion of values, we may examine actual prices as shown in the following table. The totals of 241 falls collated by Cohen and 366 by Ward, are here increased to 465. To facilitate comparisons with former periods, the collating rules of Ward are observed:

Only specimens under 400 grams weight are included.

Original sales by the finder are excluded.

The catalogue price *per gram* of a fall is determined by dividing the total price of the catalogued specimens by the total weight.

The following prices are, in the opinion of the writer, abnormally high and often erroneous. They were excluded from the collation because based on comparatively insignificant material, generally fragmentary. They are more than 50 per cent. higher than the next lower price collated for the same fall: Benares, $3.00; Bischtübe, 44 cents; Bjurböle, 59 cents; Bluff, 15 cents; Brenham, 30 cents and 40 cents; Canyon Diablo, 19 cents; Charcas, 37 cents; Cosby's Creek, 25 cents; Crab Orchard, 25 cents; Doña Inez, 27 cents; Estacado, 12 cents; Estherville, 44 cents; Hessle, 76 cents; Homestead, 36 cents; Kernouvé, $1.00; Kesen, 73 cents; Kuleschovka, $6.00; Medwedewa, 60 cents; Mincy, 31 cents; Nelson County, 63 cents; Ness County, 16 cents; Nocoleche, 75 cents;



r = 0.987 60.0
#750.
Hinrichs' Demonstration,
by "Reductio ad absurdum":
Br = 80, exactly.
analytical excess, e
Ana-lytical(?) Ratio, r.
Units of the 5th decimal
εBr in thousandths.
Pertur-bation.
A
B
C
D
W = Grammes Br taken.
Resulting f(W):
e = 0.113 (75 − W)
εBr = Ee = 33⅓ e =
= 3.76 (75 − W).
∴ Br = 80 + 3¾ (75 − W) thousandths, approximately,
which is absurd, Br being a constant.
Atomic Ratio:
R = Br/HBr = 80/81.008 = 0.987 55.7
Weber's Determinations:
Jrnl. Am. Chem. Soc., 1912, p. 1309.
"Voilà, comme on dit en mathématiques, jugée par la réduction ad absurdum la méthode de l'école dominante, consistant à accepter une de ces moyennes comme poids atomique. Chimiquement, cette école a imposé ses propres erreurs systématiques pendant tout le dernier demi-siècle aux chimistes du monde entier pour la réduction des travaux de laboratoire." p. 1229.
Hinrichs, (Comptes rendus, t. 154, séance du 6 mai 1912.)
r = 0.987 50.0

Saline, 79 cents; Trenton, 23 cents and 42 cents; Wichita, 35 cents; Zaborsika, $8.00; Zacatecas, 78 cents.

No prices are omitted from the collation because of being too low. The following however are some of those which are more than 50 per cent. lower than the next higher price or Wülfing's value, where no other price is given. In the writer's opinion these figures are too low. Nearly all are for fragments of a few grams. Bath, 20 cents; Black Mt., 33 cents; Bustee, $1.00; Copiapo, 33 cents; Dalton, 6 cents; El Capitan, 11 cents; Harrison Co., $1.00; Ibbenbühren, $1.50; Le Pressoir, $1.25; Mantos Blancos, 38 cents; Motta di Conti, 38 cents; Nammianthal, 75 cents; Orvinio, $1.20; Pipe Creek, 17 cents; Pirgunje, $1.50; Reed City, 13 cents; Richmond, $1.20; St. Denis Westrem, $1.00; Salt River, 91 cents; Uden, $2.00; Yatoor, 33 cents. The lowest Toluca price is based on several slices. One small complete mass listed in the same catalogue at 1 cent per gram is excluded. The iron-shales resulting from the oxidation of the Canyon Diablo and Augustinovka irons are omitted. The Wülfing (1897) exchange values of the following falls are not quoted, as their subsequent re-classification probably gave them new group weights: Barratta, Carlton, Eagle Station, Crab Orchard, Dakota, Imilac, Kendall County, Mejillones, Salt River, Shingle Springs, Summit and Zaborzika. Wülfing's value for Fisher is omitted, being erroneous because based on incomplete data.

Only seven dealers issue catalogues. Two American and one European publication have names and prices printed and are not annual, being dated 1912, 1907 and 1908 respectively; two European have names printed but prices written in, while two small European lists were merely typewritten.

ROSE-TSCHERMAK-BREZINA SYMBOLS.[6]

A	Angrite
a	veined
Am	Amphoterite
b	breccia-like
Bu	Bustite
C	Chondrite
c	spherulitic
Ccn	Ngawite
Cco	Ornansite
Cek	Crystalline Enstatite-Anorthite Chondrite
Cg	Gray Chondrite
Cha	Chassignite
Chl	Chladnite
Co	Orvinite
Db	Ataxite, Babb's Mills group

[6] Dr. Aristides Brezina, PROC. AM. PHIL. SOC., Vol. 53, No. 176, pp. 211 to 247.

Dc	Ataxite, Cape group	m	medium
Dm	Ataxite, Muchachos group	Mg	Grahamite
Dn	Ataxite, Nedagolla group	n	Netschaevo group
Dp	Ataxite, Primitiva group	O	Octahedrite
Ds	Ataxite, Siratic group	Obc	Brecciated Octahedrite, Copiapo group
Dsh	Ataxite, Shingle Springs group	Og	Broad Octahedrite
Eu	Eukrite	Pa	Pallasite, Albach group
f	fine	Pi	Pallasite, Imilac group
ff	finest	Pk	Pallasite, Krasnojarsk group
gg	broadest	Pr	Pallasite, Rokicky group
H	Normal Hexahedrite, not granular	Ro	Rodite
Ha	Granular Hexahedrite	s	black
Ho	Howardite	Si	Siderophyre
ho	Howarditic	U	Ureilite
i	intermediate	w	white
K	Carbonaceous Chondrite	z	Zacatecas group
k	crystalline	zg	N'Goureyma group
Lo	Lodranite		
M	Mesosiderite		

The critical scrutiny to which theoretical prices are usually subjected should not be discarded in considering the following trade figures. They are not reproduced here as being true value indices in all cases, and should therefore be analyzed before accepting them as a guide in any important transfer.

The total Wülfing exchange values of 248 falls having both Wülfing and 1912 values, afford the factor 3.1904 +, when divided into the total of the corresponding medium 1912 values in the present collation. Hence the first column of figures is Wülfing's theoretical exchange index multiplied by the approximate factor 3.2.[7] Wherever Wülfing gives two figures as of equal probability, the mean is employed. If he prefers one of two given, the preferred only is used. Where he places both values within brackets as doubtful, both are omitted.

The second column of figures gives the 1899 medium market prices.

The third column gives the 1904 medium market prices.

The fourth column gives the lowest 1912 market prices.

The fifth and last column gives the medium 1912 market prices.

The highest 1912 price of any fall may be roughly calculated by comparing its lowest with its average price for 1912.

Prices are per gram in dollars, counting M4 / = 4 / — = $1.00.

[7] The approximate factor used by Cohen was 3.1 cents (13 pfgs.).

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Abert Iron; locality?...	Om	1.63	—	—	2.69	2.69
Adargas..............	Om	—	—	.18	—	—
Admire..............	Pr	—	—	.39	.09	.20
Agen................	Cia	.74	.89	1.39	.54	.77
Agram...............	Om	.26	—	10.00	—	—
Ahumada............	Pr	—	—	—	.24	.24
Aigle, see L'Aigle.						
Alais................	K	4.48	3.62	4.00	7.00	7.00
Alastoewa, see Djati Pengilon.						
Albacher Mühle, see Bitburg.						
Albareto.............	Cc	1.60	—	1.75	2.50	2.50
Aldsworth............	Cga	2.75	—	1.17	—	—
Aleppo...............	Cwb	3.55	.37	.52	—	—
Alessandria...........	Cga	2.02	—	.75	—	—
Alexejevka, see Bachmut.						
Alfianello............	Ci	.32	.16	.14	.07	.11
Algoma..............	Om	—	—	1.00	—	—
Allegan..............	Cco	—	—	.17	.18	.20
Amalia, see Mukerop.						
Amana, see Homestead.						
Ambapur.............	Cck	—	1.06	.66	—	—
Anderson............	Pk	—	—	6.50	—	—
Andover.............	Cc	—	—	1.61	—	—
Angers..............	Cwa	3.46	—	2.62	—	—
Angra dos Reis........	A	15.72	6.00	8.00	—	—
Antifona, see Collescipoli						
Apoala..............	Of	—	—	.23	—	—
Apt.................	Cga	1.60	—	1.08	1.25	1.25
Arispe..............	Ogg	—	—	.10	.10	.12
Arlington............	Om	—	.95	.46	.24	.28
Arva, see Magura.						
Asheville, see Black Mountain and Bairds Farm.						
Assisi................	Cc	1.60	1.00	.93	.68	1.06
Aubres..............	Bu	16.93	—	2.50	—	—
Auburn..............	H	.80	—	.88	1.56	1.56
Augustinovka.........	Of	—	.44	.47	.25	.26
Aumières............	Cwa	1.60	—	2.09	1.48	2.24
Ausson..............	Cc	.64	1.15	.57	.56	.68
Avilez...............	Cc	3.55	4.55	—	—	—
Babb's Mill..........	Db	.13	.70	.46	.34	.34
Bachmut.............	Cw	1.60	1.00	1.02	1.00	1.00
Bacubirito...........	Off	—	—	.22	.25	.25
Bahia, see Bendego.						
Bairds Farm..........	Om	.74	—	.55	.33	.33
Bald Eagle...........	Om	—	—	1.02	—	—
Bali Kamerun	Cs	—	—	—	6.00	6.00
Ballinoo.............	Off	—	.15	.22	.12	.18
Bandong.............	Ro	1.28	—	.75	—	—
Barbotan............	Cga	.74	1.13	.71	.56	.93
Barea................	M	1.28	—	7.50	—	—

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Barranca Blanca	Obz	—	—	.30	1.00	1.00
Barratta	Cgb	—	—	.22	.15	.15
Batesville, see Joe Wright.						
Bath	Ccb	.74	.35	.18	.20	.34
Bath Furnace	Cia	—	—	.29	.31	.31
Beaconsfield, see Cranbourne.						
Bear Creek	Of	.22	—	.78	.84	.84
Beaver Creek	Cck	1.60	.50	.28	1.00	1.00
Bella Roca	Of	.35	.24	.22	.14	.18
Benares	Cc	.96	3.00	2.07	1.89	1.89
Bendego	Og	.03	.22	.16	.08	.11
Berlanguillas	Cia	1.60	—	2.27	—	—
Bethlehem	Cck	—	—	6.50	10.00	10.00
Beuste	Cgb	1.60	—	2.00	—	—
Bialystock	Ho	6.53	—	.65	—	—
Bielokrynitschie	Cib	2.69	—	.73	.66	.78
Billings	Og	—	—	—	.20	.20
Bischtübe	Og	.26	—	.34	.10	.10
Bishopville	Chla	3.46	2.35	1.75	4.88	4.88
Bishunpur	Cs	3.97	—	3.00	—	—
Bitburg (unmelted)	Pa	—	2.40	—	—	—
Bitburg (melted)	Pa	—	—	.14	.12	.12
Bjurböle	Cca	—	—	.08	.08	.12
Black Mountain	Og	1.22	1.06	1.53	.33	.33
Blansko	Cga	2.62	—	4.75	—	—
Bluff	Ckb	.32	.15	.07	.05	.05
Bocas	Cw	—	—	5.00	—	—
Bohumilitz	Og	.19	.25	.34	.21	.31
Bois de Fontaine, see Charsonville.						
Bonanza, see Coahuila.						
Borgo San Donino	Cho	1.70	—	.75	.50	.50
Bori	Cia	1.02	1.09	.64	—	—
Borkut	Cc	1.22	1.25	.99	.80	.80
Borodino	Cgb	3.55	—	—	7.14	7.14
Botschetschki	Cg	2.75	—	2.00	—	—
Brahin	Pr	—	1.42	.80	—	—
Braunau	H	.26	.87	.78	.73	1.12
Breitenbach	Si	—	—	.35	.38	.38
Bremervörde	Ccb	.74	.95	1.10	1.28	1.28
Brenham	Pk	.10	.20	.12	.06	.11
Bridgewater	Of	.90	.39	.25	1.20	1.20
Bückeberg, see Obernkirchen.						
Burlington	Om	.45	.42	.36	.52	.53
Buschhof	Cwa	.96	2.50	.68	1.00	1.00
Bustee	Bu	9.89	—	—	1.00	1.00
Butcher Iron, see Coahuila.						
Butler	Off	—	.37	.24	.25	.25
Butsura	Ci	.45	—	.58	—	—
Cabarrus County, see Monroe.						

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1859.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Cabezzo de Mayo......	Cw	1.25	2.55	.75	4.00	4.00
Cambria.............	Of	.45	.40	.36	.74	.74
Campo del Cielo......	Ds	.06	.97	.91	.47	.47
Canellas.............	Ci	1.02	—	1.75	—	—
Cangas de Onis.......	Cgb	.93	1.02	.73	1.00	1.00
Canyon City..........	Og	—	—	—	.20	.37
Canyon Diablo.......	Og	.03	.10	.07	.03	.03
Canton..............	Ogg	—	—	.15	—	—
Cape Girardeau.......	Cc	1.63	—	.95	2.00	2.00
Cape of Good Hope....	Dc	.58	.62	.45	.41	.41
Carlton.............	Off	—	.24	.16	.10	.17
Carthage............	Om	.13	.22	.29	.19	.28
Casas Grandes........	Om	—	—	—	.13	.13
Casey County........	Og	.93	—	.65	1.37	1.37
Castalia.............	Cgb	.74	—	.82	.75	.87
Castine..............	Cwa	—	—	4.16	2.00	2.00
Central Missouri......	Ogg	—	—	.16	—	—
Cereseto.............	Ccb	1.22	1.16	1.25	—	—
Chandakapur.........	Cib	.99	—	.62	—	—
Chantonnay..........	Cgb	.67	.56	.38	.47	.54
Charcas.............	Om	.10	—	.17	.19	.21
Charlotte............	Of	.93	—	1.60	3.52	3.52
Charsonville..........	Cga	.74	1.14	.65	.49	.66
Chassigny...........	Cha	7.87	—	2.93	7.00	7.00
Château Renard......	Cia	.58	.61	.48	.42	.58
Chesterville..........	Ds	1.60	.35	.19	—	—
Chulafinnee..........	Om	.35	.55	.34	—	—
Chupaderos..........	Of	—	.41	.22	.05	.10
Claiborne, see Lime Creek.						
Clarac, see Ausson.						
Cléguérec, see Kernouvé						
Cleveland (Lea Iron)..	Om	.16	—	.30	.30	.30
Coahuila (exact loc.?)..	H	.06	—	—	.03	.03
Coahuila (Sancha Estate, Saltillo or Couch Iron).............	H	.06	.20	.15	.14	.15
Coahuila (Fort Duncan)	H	.06	.20	.09	.07	.09
Coahuila (Butcher Irons from Bonanza and Desert of Mapimi)..	H	.06	.12	.11	.08	.08
Cooke County, see Cosby's Creek.						
Cold Bokkeveldt......	K	1.86	2.25	1.38	1.33	1.44
Colfax..............	Om	—	.52	.40	.98	.98
Collescipoli..........	Cc	1.12	.75	.88	.63	.63
Concepcion, see Adargas.						
Coon Butte..........	Cib	—	—	—	.59	.59
Coopertown.........	Om	.26	—	.42	1.00	1.00
Copiapo.............	Obc	1.22	.50	1.20	.33	.33
Cosby's Creek	Og	.16	.30	.15	.10	.11
Costilla Peak.........	Om	.38	—	.14	.11	.14
Cowra..............	Off	—	2.10	2.00	—	—
Crab Orchard........	Mg	—	.12	.12	.11	.12

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Cranbourne (Beaconsfield)	Og	—	.17	.10	.11	.11
Cranbourne (Melbourne)	Og	.03	.22	.23	.05	.06
Cross Timbers, see Red River.						
Cuernavaca	Of	—	—	.12	.11	.21
Cynthiana	Cg	1.22	—	.80	1.00	1.00
Dakota	Ogg	—	—	.40	.60	.60
Dalton	Om	.19	.57	.27	.06	.23
Dandapur	Cia..	.93	—	—	1.00	1.00
Daniel's Kuil	Ck	1.57	—	3.00	5.00	5.00
Danville	Cga	2.34	—	3.00	6.00	6.00
Deep Springs	Db	—	—	.26	.30	.30
Denton County	Om	.54	—	.80	1.17	1.17
Descubridora	Om	.13	—	.15	.11	.12
Dhulia	Cwa	—	—	5.50	—	—
Dhurmsala	Ci	.45	.25	.16	.10	.20
Djati Pengilon	Ck	.22	2.00	1.00	.97	.97
Dolgovoli	Cw	2.69	—	1.13	1.00	1.00
Dona Inez	M	.58	.19	.18	.12	.15
Dores dos Campos Formosus	Cwa	—	—	—	.40	.40
Doroninsk	Cgb	1.82	2.50	1.50	—	—
Drake Creek	Cwa	.74	—	.65	.75	.75
Durala	Cia	.74	—	—	1.25	1.25
Duruma	Cia	2.02	1.07	2.00	4.00	4.00
Eagle Station	Pr	—	.49	.39	.48	.50
Ekaterinoslav, see Mordvinovka.						
Elbogen	Om	.13	.75	.85	1.00	1.15
El Capitan	Om	.51	.24	.13	.11	.11
Elgueras, see Cangas de Onis.						
Elm Creek	Cco	—	—	—	.22	.22
Emmitsburg	Om	1.60	—	1.24	5.00	5.00
Ensisheim	Ckb	.35	.62	.74	.92	.96
Epinal	Cc	2.62	10.62	—	—	—
Ergheo	Ckb	—	—	.26	.15	.19
Erxleben	Ck	.90	—	.84	1.00	1.00
Estacado	Cka	—	—	—	.05	.05
Estherville	M	.16	.19	.14	.13	.16
Farmington	Csa	.35	.19	.09	.08	.13
Favars	Ci	2.02	—	3.25	—	—
Fayette County, see Bluff.						
Fisher	Cia	—	—	.30	.35	.35
Forest	Ccb	.26	.23	.12	.08	.15
Forsyth	Cwa	.74	—	.87	2.00	2.00
Forsyth County	Dn	—	—	.19	.21	.21
Fort Duncan, see Coahuila.						
Fort St. Pierre	Om	.42	.44	.52	.59	.76
Franceville	Om	—	—	—	.10	.10
Frankfort	Ho	7.30	—	4.00	4.13	5.56

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Futtehpur	Cwa	.96	—	1.00	—	—
Ghambat	Cia	—	1.04	—	—	—
Gilgoin	Ck	—	—	.18	.11	.11
Girgenti	Cwa	.96	1.00	1.23	2.07	2.07
Glorieta Mountain	Om	.13	.25	.20	.12	.12
Gnadenfrei	Cc	1.60	5.00	—	1.00	1.00
Gnarrenburg, see Bremervörde.						
Goalpara	U	5.63	—	3.00	—	—
Goamus, see Mukerop..						
Grand Rapids	Of	.35	.16	.13	.13	.19
Great Fish River	Of	1.70	—	—	2.50	2.50
Grosnaja	Cs	.96	3.25	2.07	1.00	1.00
Gross-Liebenthal	Cwa	.93	1.75	.89	.50	.88
Grüneberg	Cga	2.02	—	1.00	—	—
Guareña	Ck	.58	—	1.50	—	—
Hainholz	M	.45	—	.35	.38	.38
Harrison County	Cho	2.43	—	—	1.00	1.00
Hartford (Linn County) see Marion.						
Heredia	Ccb	2.02	—	—	3.50	3.50
Hessle	Cc	.45	.89	.44	.38	.42
Hex River	H	.35	.14	.17	.50	.50
Holbrook	Cck	—	—	—	.09	.09
Holland's Store	Ha	.93	—	.37	—	—
Homestead	Cgb	.22	.15	.15	.10	.15
Honolulu	Cwa	.96	1.31	1.18	2.00	2.00
Hopper	O	—	—	1.20	—	—
Hraschina, see Agram.						
Huejuquilla, see Chupaderos.						
Hungen	Cga	4.70	—	4.00	—	—
Hvittis	Cck	—	—	—	.98	.98
Ibbenbühren	Chl	4.35	—	1.50	1.50	1.50
Ilimaë	Om	.38	—	—	.25	.25
Imilac	Pi	—	.34	.13	.17	.19
Inca, see Llano del Inca.						
Indarch	Kca	1.60	2.32	2.17	.89	.89
Independence, see Kenton County.						
Indian Valley	Ha	—	—	—	.74	.74
Indio Rico	Ck	—	—	—	2.50	2.50
Iquique	Dc	2.43	—	.90	—	—
Iredell	H	—	—	—	1.49	1.49
Ivanpah	Om	.26	—	.65	.14	.14
Jackson County	Om	1.63	—	—	3.03	3.03
Jamestown	Of	1.28	.36	.28	.43	.62
Jamyscheva, see Pavlodar.						
Jelica	Am	.96	.37	.38	1.50	1.50
Jenny's Creek	Og	.64	.66	.53	.30	.39
Jerôme	Cck	—	—	.60	.20	.20
Jewell Hill	Of	.45	1.57	.77	.75	.75
Joel's Iron	Om	.74	1.70	—	1.67	1.67
Joe Wright Mountain	Om	.19	.37	.24	.29	.29

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Jonzac	Eu	1.89	—	2.25	—	—
Juncal	Om	.16	.96	.52	—	—
Juvinas	Eu	.58	1.11	1.80	.49	.53
Kaande, see Oesel.						
Kaba	K	2.08	—	2.74	—	—
Kakangarai	Stone	—	—	1.86	—	—
Kansada, see Ness County.						
Karakol	Cw	2.75	—	2.00	—	—
Karand, see Veramin.						
Kendall County	Hb	—	.26	.22	.18	.25
Kenton County	Om	.16	.16	.09	.06	.07
Kermichel	Ck	—	—	—	1.48	1.48
Kernouvé	Cka	.35	.67	.51	.42	.46
Kesen	Ccb	.93	.52	.26	.13	.18
Khairpur	Ck	.58	—	1.71	1.67	1.67
Kilbourn	Cga	—	—	—	4.67	4.67
Kingston	Om	—	—	—	.40	.40
Klein Menow	Cck	1.60	1.30	—	1.23	1.23
Klein Wenden	Ck	.93	—	.74	—	—
Knyahinya	Cg	.19	.17	.13	.08	.13
Kodaikanal	Obk	—	—	—	.60	.60
Kokomo	Dc	2.02	—	—	4.31	4.31
Kokstad	Om	.51	.50	—	—	—
Krähenberg	Cho	.99	—	3.00	—	—
Krasnojarsk, see Medwedewa.						
Krawin, see Tabor.						
Kuleschovka	Cwa	.74	—	—	1.00	1.00
La Baffe, see Epinal.						
La Bécasse	Cw	2.75	—	1.04	—	—
Laborel	Cib	—	1.25	1.00	—	—
La Caille	Om	.06	.64	.78	.79	.79
La Grange	Of	.35	—	.37	.60	.60
L'Aigle	Cib	.74	.39	.29	.18	.20
Lancé	Kc	.54	—	1.30	.90	.95
Lançon	Cia	—	1.06	.82	.82	.91
La Primitiva	Dp	1.09	1.06	—	—	—
Lasdany, see Lixna.						
Laurens County	Of	—	—	.90	—	—
Lea Iron, see Cleveland.						
Leighton	Cgb	—	—	—	2.86	2.86
Lenarto	Om	.16	.50	.23	.25	.29
Le Pressoir	Cc	2.02	4.25	2.52	1.25	2.12
Les Ormes	Cw	7.87	—	4.00	—	—
Lesves	Cw	—	1.32	1.13	—	—
Le Teilleul	Ho	9.89	—	3.00	—	—
Lexington County	Og	.54	—	.25	.27	.27
Lick Creek	H	.99	1.25	—	—	—
Lime Creek	H	.22	.75	.24	.21	.21
Limerick	Cgb	.51	—	1.19	.83	.83
Linn Co., see Marion.						
Linnville	Db	7.65	—	1.50	6.00	6.00
Lion River	Of	.26	.64	.38	.38	.38

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Lissa	Cwb	.58	1.22	.97	—	—
Little Piney	Cc	—	—	—	5.00	5.00
Lixna	Cga	.74	1.56	.81	1.00	1.00
Llano del Inca	M	.74	.14	.13	.04	.07
Lockport, see Cambria.						
Locust Grove	Ds	—	.27	.15	.38	.38
Lodran	Lo	15.71	5.65	3.65	—	—
Long Island	Cia	.32	.11	.09	.08	.10
Losse, see Barbotan.						
Losttown	Om	.54	.34	.26	—	—
Lucky Hill	Om	.77	—	—	1.00	1.00
Luis Lopez	Om	—	—	.28	.25	.27
Macao	Cia	1.22	—	1.75	2.86	2.86
Macquaire River	M	—	—	—	.91	.91
Madoc	Of	.22	1.25	—	—	—
Maêmê	Cia	—	.59	.63	1.50	1.50
Magura	Og	.13	.15	.09	.10	.10
Mainz	Cia	—	1.27	1.10	—	—
Manbhoom	Am	2.62	2.52	2.10	2.14	2.55
Mantos Blancos	Of	.99	—	—	.38	.95
Marion	Cwa	.67	.55	.30	.30	.37
Marjahlatti	Pi	—	—	—	.44	.44
Mart	Off	—	—	.57	—	—
Mauerkirchen	Cw	.99	1.84	.79	—	—
Mazapil	Om	.77	—	3.40	5.59	5.59
McKinney	Cs	.86	.17	.16	.08	.12
Medwedewa	Pk	.10	.47	.22	.24	.25
Mejillones	Mg	—	—	.20	1.00	1.00
Menow, see Klein Menow.						
Merceditas	Om	.19	.31	.35	.25	.29
Mern	C	—	—	—	.71	.71
Mezö-Madaras	Cgb	.45	1.75	.72	.31	.31
Mhow	Ci	3.55	—	.85	—	—
Midt Vaage, see Tysnes.						
Mighei	K	1.60	3.00	1.79	1.24	1.25
Mikenskoi, see Grosnaja						
Milena	Cw	1.60	1.45	.97	1.00	1.00
Minas Geraes	Cwa	2.18	—	—	1.82	1.82
Mincy	M	.26	.17	.17	.14	.17
Misshof	Cc	1.22	.95	.64	.64	.67
Misteca	Om	.22	.35	.14	.11	.18
Mocs	Cwa	.26	.11	.08	.08	.10
Modoc	Cwa	—	—	—	.40	.41
Molina	Cgb	.35	—	2.85	2.50	2.50
Monroe	Cga	.86	.67	.69	.90	.95
Mooranoppin	Ogg	—	.95	.62	—	—
Mooresfort	Ccb	.96	1.85	1.13	2.00	2.00
Mordvinovka	Cw	1.31	—	—	1.25	1.85
Morristown	Mg	—	.20	.14	.12	.21
Motta di Conti	Cc	1.28	—	.57	.38	.38
Mount Browne	Cc	—	—	—	1.47	1.47
Mount Joy	Ogg	.26	.05	.10	.06	.08
Mount Stirling	Og	—	.22	.17	.17	.17
Mount Vernon	Pk	—	—	—	.36	.36

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Muchachos, see Tucson.						
Mukerop (exact loc. ?)	Off	—	—	.10	.10	.12
Mukerop (Amalia Farm)	Off	—	—	—	.04	.04
Mukerop. (Goamus)	Off	—	—	—	.06	.06
Mungindi	Off	—	.25	.19	.15	.19
Muonionalusta	Of	—	—	—	.75	.75
Murfreesboro	Om	.45	1.27	.32	1.27	1.27
Murphy	H	—	—	.22	.14	.14
Nagaya	K	2.08	1.85	—	1.50	1.75
Nagy-Vazsony	Om	1.02	—	.70	—	—
Nammianthal	Cca	2.75	—	—	.75	.75
Nanjemoy	Cc	.96	.70	1.25	2.86	2.86
Nejed	Om	.19	—	.33	.11	.11
Nelson County	Ogg	.45	.25	.16	.12	.19
Nenntmansdorf	H	.45	—	.55	—	—
Nerft	Cia	.74	.85	.69	.75	.75
Ness County	Cib	—	.25	.12	.07	.07
Netschaëvo, see Tula.						
New Concord	Cia	.26	.62	.31	.22	.38
Newton County, see Mincy.						
Ngawi	Ccn	5.79	3.84	1.80	—	—
N'Goureyma	Obzg	—	—	—	.33	.33
Niagara	Og	—	—	—	.50	.50
Nobleborough	Ho	15.71	—	3.50	—	—
Nocoleche	Om	—	.60	.25	.28	.39
Novo-Urei	U	5.63	4.00	3.58	2.25	3.12
Nulles	Cgb	.93	—	3.00	—	—
Oakley	Ck	—	—	.14	—	—
Obernkirchen	Of	.35	.65	.37	.75	.75
Ochansk, see Tabory.						
Oesel	Cw	1.89	1.20	1.10	.72	.87
Okniny	Cgb	2.62	—	2.12	1.50	1.50
Old Fork, see Jenny's Creek.						
Orange River	Om	.16	.71	.82	—	—
Orgueil	K	1.28	1.47	.82	.50	.75
Ornans	Cco	3.39	2.50	1.62	4.00	4.00
Oroville	Om	—	—	.44	.22	.22
Orvinio	Co	4.48	1.32	1.69	1.20	2.15
Oscuro Mountains	Og	—	.47	.38	.25	.49
Ottawa	Cho	—	2.75	—	—	—
Pacula	Cwb	4.13	1.09	.74	1.00	2.00
Pallas, see Medwedewa.						
Parnallee	Cga	.35	.40	.51	.34	.52
Pavlodar	Pk	.74	1.15	.90	.64	.66
Pavlovka	Ho	5.79	—	1.08	—	—
Penkarring Rock, see Youndegin.						
Petersburg	Ho	6.62	—	—	10.00	10.00
Petropavlovsk	Om	.58	—	2.29	—	—
Pila, see Rancho de la Pila.						
Pillistfer	Ck	.35	.95	.95	.69	.82

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Pipe Creek	Cka	2.69	.32	.14	.17	.17
Pirgunje	Cwa	3.97	—	—	1.50	1.50
Pittsburg	Ogg	—	—	1.14	—	—
Ploschkowitz	Ccb	—	—	—	10.00	10.00
Plymouth	Om	1.09	.24	.18	.18	.26
Politz	Cwa	.96	1.87	1.10	—	—
Powder Mill Creek, see Crab Orchard.						
Prairie Dog Creek	Cck	5.12	.60	—	—	—
Prascoles, see Zebrak.						
Primitiva, see La Primitiva.						
Pultusk	Cgb	.19	.07	.05	.05	.07
Puquios	Om	.35	.65	.57	.57	.57
Putnam County	Of	.45	.60	.56	.89	.89
Quenggouk	Cc	.74	1.07	.79	1.00	1.00
Rakovka	Ci	1.22	—	1.43	.80	.80
Ranchito, see Bacubirito.						
Rancho de la Pila	Om	.19	.64	.17	.18	.18
Rasgata	Ds	.06	—	.32	.42	.59
Red River	Om	.06	.25	.35	.37	.37
Reed City	Om	—	—	.15	.13	.26
Renazzo	Cs	1.12	2.50	1.79	—	—
Rhine Valley	Om	—	—	.25	.50	.50
Richmond	Cck	3.10	—	2.11	1.20	1.20
Rittersgrün, see Steinbach.						
River Brazos, see Wichita.						
Rochester	Cc	3.04	—	2.58	—	—
Roda	Ro	10.14	—	6.00	—	—
Rodeo	Om	—	—	—	.15	.23
Roebourne	Om	—	.20	.14	.10	.13
Rokicky, see Brahin.						
Roquefort, see Barbotan.						
Rosario	Og	—	.92	.38	.29	.29
Rowton	Om	.54	—	3.30	—	—
Ruff's Mountain	Om	.19	.45	.34	.21	.23
Russel Gulch	Of	.58	—	.47	.96	.96
Sacramento Mountains	Om	—	—	.11	.08	.08
Saint Denis Westrem	Cca	3.39	3.12	2.81	1.00	1.00
Saint Francois County	Og	.54	.35	.28	.38	.38
Sainte Genevieve Co.	Of	—	—	.12	.11	.11
Saint Mesmin	Cib	1.57	2.12	.68	1.41	1.41
Saline	Cck	—	—	—	.20	.21
Salles	Cia	.96	—	—	1.00	1.00
Saltillo, see Coahuila.						
Salt Lake City	Cgb	2.75	—	—	1.00	1.00
Salt River	Off	—	—	—	.91	1.45
San Angelo	Om	—	.15	.12	.10	.11
Sancha Estate, see Coahuila.						
Santa Apolonia	O	—	—	—	.05	.05

Name (Locality).	Symbol	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Santa Rosa	Obz	—	—	—	.15	.15
Sao Juliao de Moreira	Ogg	.35	.15	.12	.11	.13
Sarbanovac, see Soko-Banja.						
Sarepta	Og	.35	.32	.51	.31	.31
Saurette, see Apt.						
Savtschenskoje	Cck	5.12	2.50	2.10	—	—
Schönenberg	Cwa	.93	2.36	2.62	—	—
Scottsville	H	.45	.22	.15	.25	.37
Searsmont	Cc	1.60	—	2.98	2.61	2.61
Seeläsgen	Ogg	.45	.27	.17	.13	.16
Segowlee	Ck	.74	—	—	.71	.71
Seneca Falls	Om	.54	—	.61	.73	.73
Senegal River	Ds	.74	.50	1.00	2.00	2.00
Senhadja	Cwa	.74	—	.75	.59	.79
Seres	Cg	.93	—	1.10	—	—
Sevrukovo	Cs	.45	2.20	2.01	—	—
Shalka	Chl	3.46	2.81	—	2.00	2.00
Shelburne	Cg	—	—	—	.25	.46
Shingle Springs	Dsh	—	.75	—	.50	.65
Siena	Ch	1.28	2.31	2.13	—	—
Silver Crown	Og	.45	.34	.26	.22	.24
Siratik, see Senegal.						
Sitathali	Cho	2.14	—	1.00	—	—
Slobodka	Cc	3.97	—	—	3.00	3.00
Smith's Mountain	Of	.93	—	1.08	—	—
Smithville	Og	.26	.13	.11	.09	.09
Soko-Banja	Cc	.45	.46	.41	.29	.38
Ställdalen	Cgb	.45	.79	.65	.40	.49
Stannern	Eu	.74	.51	.34	.39	.40
Staunton	Om	.16	.22	.18	.09	.15
Stavropol	Ck	1.25	—	2.58	1.00	1.00
Steinbach	Si	.58	.51	.46	.34	.36
Stutsman County, see Jamestown.						
Summit	Ha	—	—	—	5.47	5.47
Tabor	Ccb	.74	1.09	1.05	.76	.93
Tabory	Ccb	.26	.25	.27	.14	.20
Tadjera	Ct	3.39	3.00	—	5.00	5.00
Taney County, see Mincy.						
Tazewell	Off	—	.66	.36	.32	.32
Tennant's Iron	Og	—	—	—	.75	.75
Tennasilm	Cca	.93	2.02	1.05	1.00	1.00
Thunda	Om	.26	.45	.20	.15	.17
Thurlow	Of	—	.66	—	—	—
Tieschitz	Cc	.54	2.07	—	—	—
Timochin	Cc	.35	—	.73	.74	.87
Tjabe	Ck	.45	—	.85	1.00	1.00
Toluca	Om	.06	.05	.06	.02	.04
Tomatlan	Cc	—	—	—	1.50	1.50
Tombigbee R. (Jachin)	Ha	—	—	—	.21	.21
Tomhannock Creek	Cgb	1.60	1.95	1.59	.50	2.25
Tonganoxie	Om	—	.32	.16	.22	.22
Torre, see Assisi.						

Name (Locality).	Symbol.	Wülfing Exchange Value 1897.	Cohen Collation, Med. 1899.	Ward Collation, Med. 1904.	Foote Collation, Lowest.	Foote Collation, Med. 1912.
Toubil	Om	—	—	—	.71	.73
Toulouse	Cia	2.62	—	—	—	—
Tourinnes-la-Grosse	Cw	1.44	1.50	.87	.88	1.03
Trenton	Om	.19	.31	.17	.14	.14
Trenzano	Cca	.99	.72	.70	.64	.79
Tucson	Dm	.06	.68	.33	—	—
Tula	Obn	2.69	.95	.76	.62	.84
Tysnes	Cgb	.54	.85	.53	.38	.62
Uden	Cwb	4.35	—	2.25	2.00	2.00
Union County	Ogg	1.28	—	1.12	.67	1.06
Utah, see Salt Lake City						
Utrecht	Cca	1.25	2.25	.83	.50	.75
Vaca Muerta	Mg	.35	.59	1.03	.26	.26
Vavilovka	Ro	—	—	—	5.00	5.00
Veramin	M	1.57	6.25	2.81	1.78	2.20
Verkhne Dnieprovsk	Off	—	.87	—	.50	.50
Verkhne Udinsk	Om	.26	.49	.50	.43	.46
Victoria	Om	.22	4.20	.61	2.80	2.80
Vigarano Piave	K	—	—	—	.25	.25
Virba	Cwa	1.63	.50	—	—	—
Vouillé	Cia	.58	1.27	.77	.50	.73
Waconda	Ccb	.58	.47	.19	.12	.15
Wairarapa	C	—	—	—	1.50	1.50
Waldron Ridge	Og	.58	—	.22	—	—
Walker County	H	.22	—	—	.65	.65
Walker Township, see Grand Rapids.						
Warrenton	Cco	4.48	1.80	1.31	4.00	4.00
Welland	Om	.35	.25	.28	.34	.41
Werchne Dnieprowsk, see Verkhne Dnieprovsk.						
Werchne Udinsk, see Verkhne Udinsk.						
West Liberty, see Homestead.						
Weston	Ccb	.58	.60	.45	.50	.54
Wichita	Og	.13	.30	.17	.16	.19
Willamette	Om	—	—	—	.17	.17
Williamstown	O	—	—	—	.19	.22
Winnebago County, see Forest City.						
Wirba, see Virba.						
Wittness	Cc	1.60	2.25	—	2.50	2.50
Wold Cottage	Cwa	.45	—	1.27	2.60	2.60
Yanhuitlan, see Misteca.						
Yardea Station	Om	—	—	2.08	—	—
Yarra Yarra River, see Cranbourne.						
Yatoor	Cc	.74	1.29	—	.33	.33
Youndegin	Og	.10	.34	.17	.12	.14
Zaborzika	Cwa	—	—	—	1.00	1.00
Zacatecas	Obz	—	.40	.24	.07	.19
Zavid	Cia	—	.75	.40	.25	.30
Zebrak	Cc	1.60	2.10	—	—	—

Price Changes.—In comparing the medium prices of 190 falls collated alike by Cohen, Ward and Foote, we find that the average medium price decreased 27.4 per cent. from 1899 to 1904, and increased 18.6 per cent. between 1904 and 1912. Of all the falls collated in 1912, the following 52 have advanced in price more than one half since 1904: Alais, Auburn, Barranca Blanca, Bath, Beaver Creek, Bethlehem, Bishopville, Bridgewater, Cabezzo de Mayo, Cambria, Cape Girardeau, Casey County, Charlotte, Chassigny, Colfax, Coopertown, Cuernavaca, Daniel's Kuil, Danville, Duruma, Emmitsburg, Forsyth, Girgenti, Hex River, Honolulu, Jamestown, Jelica, La Grange, Linnville, Locust Grove, Macao, Maêmê, Mazapil, Mejillones, Mooresfort, Murfreesboro, Nanjemoy, Nocoleche, Obernkirchen, Ornans, Pacula, Putnam County, Rasgata, Reed City, Rhine Valley, Russel Gulch, Saint Mesmin, Scottsville, Senegal River, Victoria, Warrenton, Wold Cottage.

The following seventeen have decreased in price more than one half since 1904: Bischtübe, Black Mountain, Cañon Diablo, Castine, Chupaderos, Copiapo, Cranbourne (Melbourne), Grosnaja, Indarch, Ivanpah, Jerome, Juvinas, Mezö-Madaras, Nejed, Saint Denis Westrem, Stavropol, Vaca Muerta.

Rare Falls Become Less Available.—As a small meteorite is distributed among institutions which often acquire even less than they desire for their own purposes, it becomes increasingly difficult for others to secure it. Thus, of the 121 meteorites collated by Cohen in 1899 at 65 cents per gram or over, 29 per cent. are not in the 1912 market, whereas of the 120 collated at less than 65 cents, only 6 per cent. have disappeared from current catalogues.

The Cause of High Prices.—On this point an examination of Cohen's collation affords some interesting evidence. He collated 109 meteorites in 1899 which had been recorded by Wülfing in 1897, and of which the major part of each was held by one owner. Classifying them we find that:

1. Seven falls were quoted by four dealers controlling one to two falls each, at figures averaging 68 per cent. lower than Wülfing's values.

2. Sixty-one falls controlled by institutions or private indi-

viduals, were commercially quoted at figures averaging 5 per cent. lower than Wulfing. They controlled one to three falls each.

3. Forty-one falls controlled by the three oldest and largest institutional collections, were commercially quoted at figures averaging 45 per cent. higher than Wülfing. They controlled 8, 12 and 21 falls respectively.

These figures require some analysis before acceptance. It should be emphasized that they are not necessarily institutional prices, but rather prices asked by dealers for institutionally controlled falls.

We have noted that the sixty-one falls controlled by the smaller institutional and private collections afforded market prices 5 per cent. below Wülfing. That meant that their need of each fall controlled was less than the need of the "big three" institutions, whose controlled falls found market prices 45 per cent. higher than Wülfing. The smaller holders let their surplus stock go at low figures on exchange, being eager to advance the growth of their collections, or because they had merely local holdings of a nearby fall, or again because they were uninformed on values. The larger institutional owners, on the contrary, were probably well informed about relative values. Accordingly they parted with their surplus only on the most attractive offers. Moreover they required a larger proportion of each fall than did the smaller collections and had correspondingly less to part with, thus tending to advance the price. Summed up, the price of any fall depends somewhat on how willing the controlling owner is to part with his property, the demand being fully established. However, as with all commodities, such demand varies inversely with the price.

The Use of Wülfing's Tables.—In accepting the much criticized Wülfing formula as the only theoretical system of evaluation yet devised, one must do so with clearly expressed conditions.

Since some of Wülfing's critics apparently take his approximations as more exact than he intended them to be, let us in fairness read his words on p. 431. "Even though I only succeed in establishing the standard of value to such an extent that one may at least say: the value of such a meteorite is not more than double nor less

than half the given figure—even that would be an advance over the present fearful confusion prevailing on questions of value." While Wülfing's formula has a large probability of error on account of his exclusion of several highly important factors, it must be remembered that without it or some similar system, meteorites would be valued by a "rule of thumb," the elasticity of which is frequently felt in the wide limits shown by exchange and market prices.

It is certain that Wülfing's work has lessened the absurd variations in value which abound in exchanging, and that it has also aided in regulating trade prices. It is therefore to be hoped that a new edition may be published in the not distant future. Nearly two hundred meteorites are known besides the 536 which he recorded, while the number of owners has increased. Unfortunately, Professor Wülfing replies, in response to a query, that he does not contemplate a revision.

Conclusion.—In the writer's opinion, no holder of a meteorite should divide it before considering current trade prices of similar falls, a practice which is already established in the present wide use of previous collations. Likewise he should consult Wülfing's tables, which are based on present known weight, group weight and number of owners. Finally, the exchanger should estimate the importance of the following factors: Weight of specimen offered; observation of fall; area of slice offered; phenomenal variation between individual specimens; distinctness of structure; missing portions; historical interest.

It is certain that the stabilizing influence of a fuller consideration of values by meteorite exchangers will tend to dispel an already lessening hesitation among institutional owners, and result in that freer distribution which Buchner and Wülfing sought to bring about. With its achievement, the advancement of this unfamiliar but growing science will have been distinctly furthered.

THE TRUE ATOMIC WEIGHT OF BROMINE.

(PLATES XXXIV.-XXXVI.)

BY DR. GUSTAVUS HINRICHS.

(*Read April 4, 1913.*)

Highly important laboratory work, undertaken for the purpose of determining the atomic weight of bromine, has quite recently been done by Dr. H. C. P. Weber.[1] Ten complete syntheses of hydrogen bromide were made, taking from 60 to 80 grammes of bromine for the individual determinations.

Employing the method of reduction in general use by the dominant school, Mr. Weber finds the atomic weight of bromine to be 79.924 with the insignificant "*probable error*" of 0.0014, oxygen at 16 exactly being taken as the standard.[2] Accordingly, the atomic weight of bromine should fall between 79.923 and 79.925, for $O = 16$.

Now bromine is one of the ten fundamental elements of the system of Stas (Ag, Pb, Na, Ka; Cl, Br, Io; N, S, O). If the above value for Br should be found to be in error, such error would affect the values of most of the other nine elements also.

During the last twenty years, I believe to have demonstrated,[3] by close mathematical examination of all the atomic weight determinations made during the entire century (since Berzelius began this work in 1810) that the method in common use for the *reduction* of

[1] *Jrnl. Am. Chem. Soc.*, Oct., 1912, pp. 1294–1310.

[2] *L. c.*, pp. 1309–1310.

[3] *Special Works:* "True Atomic Weights," 1894; "Absolute Atomic Weights," 1901; "Proximate Constituents," 1904. *Twenty-five Notes* in the *Comptes Rendus*, in twelve years from 1892 to 1912; (in nine years no note on atomic weights); *Moniteur Scientifique*, thirteen papers from 1906–1909; *Revue générale de Chimie*, 1910, on hydrogen; *Proceedings American Philosophical Society*, 1910, 1911; *Proceedings Am. Assoc. Adv. Science*, 1869.

the laboratory work done is not correct but false in principle and erroneous in its results.

Very naturally the dominant school has first denounced my work and thereafter ignored the same; nevertheless it has been compelled to admit the existence of grave errors in the results of Stas which had been extolled to be of astronomical precision. This applies especially to the most famous of the fundamental determinations of Stas, namely those of Ag and N. For nitrogen, Stas gave the value 14.044 exactly. By a marvelous series of decimals (from 38 to 375 places furnished him by A. Quetelet) he declared the lowest *possible* value to be 14.040; at present, the school of Stas has come down to 14.008 which is one fifth of the lowest possible value of Stas and only 8 thousandths above the value we believe to have proved to be the true value, namely 14 *exactly*.[4] For silver the value of Stas has been reduced by his school from 107.930 to 107.880, which is a reduction of fifty thousandths. It must be borne in mind that this matter is a question of high precision, questioning the thousandths of the unit of atomic weights.

All the above values refer to the oxygen standard in common use, O = 16 exactly, for which we believe to have proved that Ag is 108 *exactly* and Br 80 *exactly*. Hence the present values of the dominant school would be 0.120 low for Ag, *i. e.,* 0.11 per cent. of 108; and 0.076 low for Br, *i. e.,* 0.10 per cent. of 80.

If our results are correct, the dominant school is *one tenth of one per cent. low* on the atomic weight of these two fundamental elements.

Accordingly, if our work be true, all the quantitative chemical analyses made in the chemical laboratories throughout the world, from the lowest technical to the highest scientific institutions, have for half a century been falsified (unintentionally, of course, but de facto) to the extent of *one tenth of one per cent.* for both silver and bromine determinations. For lithium, the error committed is now fully one per cent.

[4] The experiments of Guye and his students at Geneva are claimed to prove N = 14.008; but each set of determinations has been made within very narrow limits and with small weights at that, except those of 1912, which positively prove N = 14.000, as I have shown (*Comptes Rendus*, May 6, 1812; T. 154, p. 1227).

The question here raised is therefore of the highest practical as well as scientific importance; most assuredly, it cannot be settled by a ballot, though such has recently been taken. Nor should it be left to the decision of a select few for each country, but every individual chemist should, on this as on any other important chemical question, try to study sufficiently to enable him to form an opinion of his own.

To facilitate such a study on the part of the individual chemist, we here present the laboratory work of Mr. Weber on bromine in the most simple and direct way possible, without any refined technicalities: *simply plotting the experimental results themselves* (the ratios of the actual weights) *according to the weight of the bromine taken and the ratios found in each case.*

When the individual chemist inspects this diagram of the actual weights taken and the ratios found, he will realize that we have neither hypotheses to make nor theories to defend. We simply have tried to look at the actual experimental data obtained in the laboratory itself. We have divided the entire process into twelve consecutive steps, each one being distinct and preparatory to the next.

I. The Weights, Taken and Found.

TABLE I.

Weights, in Grammes, to One-tenth Mgr.

No.	H	Br	HBr	Discrepancy,[5] Mgr.
1	0.7730	61.2884	62.0605	−0.85
2	0.8606	68.2503	69.1114	0.54
3	0.7761	61.5573	62.3220	−1.42
4	0.9693	76.8822	77.8514	−0.15
5	1.0755	85.2956	86.3709	−0.15
6	0.9969	79.0683	80.0642	−0.99
7	0.7497	59.4528	60.2050	2.59
8	0.9816	77.8555	78.8376	0.43
9	1.0013	79.3963	80.3966	−0.06
10	0.8198	65.0214	65.8387	−2.56
Sum	9.0037	714.0572	723.0583	−2.63
Means	0.9004	71.4057	72.3058	−0.26

[5] The discrepancy is: HBr — (H + Br) and its theoretical value is 0, of course. The actual value is once over 1 and twice over 2 mgr.: hence the hundredth mgr. of weighings have properly been dropped by me in copying the weights given by Weber.

II. The Analytical Ratio.

TABLE II.

The Analytical Ratio, r; Calculated to 6 Decimals, the Sixth as First to the Fifth, Since Ordinarily Only Fifth is Taken.

	Ratio:	1st	2d	3d
	Br (to 1st dec.)	H/Br	H/HBr	Br/HBr
1	61.3	0.012 61.2	0.012 45.6	0.987 55.8
2	68.3	60.9	45.2	56.3
3	61.4	61.0	45.3	57.1
4	76.9	60.7	45.1	55.1
5	85.3	60.9	45.2	55.0
6	79.1	60.8	45.1	56.2
7	79.5	61.0	45.2	50.6
8	77.9	60.8	45.1	54.3
9	79.4	61.1	45.4	55.8
10	65.0	60.8	45.2	58.6
Mean	71.4	60.9	45.2	55.5
Range	23.8	0.4	0.5	8.0

Remarks.—(1) Ratios very concordant; range small, especially in first and second (five significant digits only), less so in third (six significant digits). (2) The reciprocal ratios of nos. 1 and 2 would magnify the minute error in H eighty-fold. (3) Complete synthesis gives the three equally important ratios; Weber omits no. 3.

III. The Variation of the Analytical Ratio.

As soon as the individual determinations of the analytical ratio r (Table II.) are plotted according to a convenient scale it is seen that this ratio is not constant, but variable. In our drawing (No. 750) the abscissæ represent the weight w of bromine taken on the scale of a centimeter to the gramme, while the ordinates represent the corresponding ratio r on the scale of one inch to the unit of the *fifth* decimal; that is, the unit-ratio itself is 100,000 inches which is 8,333 feet or 1.58 english mile. Of the three distinct diagrams we shall here insert only the one representing the third ratio, Br/HBr, which is the sharpest and therefore the most decisive. The reduction to centimeter scale by photography is here inserted; for this cut the unit ratio is therefore one kilometer, and the unit of the fifth decimal one centimeter. The gramme is represented by nearly four millimeters. See Plate XXXIV.

Each full black circle represents the determination identified by the same numeral used by Mr. Weber.

The single determinations for less than 60 (no. 7) and for more than 80 grammes (no. 5) of bromine give the mean *d* of comparatively little importance.

The eight determinations made with between 60 and 80 grammes of bromine fall in two well-defined groups of four determinations each and give the equally important two mean values marked *A* (1, 3; 2, 10) and *B* (4, 8; 6, 9) of which *C* is the final mean.[6]

But it is clear that this mean *C* cannot be considered to be the true mean value of the ratio *r* because it is nothing more than the mean of eighth determinations which Mr. Weber made with the eighth weights of bromine which he "happened to take." For as a matter of fact, the eight determinations do not give some constant value from which the individual determinations differ by small deviations equally distributed as to amount and sign. On the contrary, the eight determinations form a well-defined straight line *A–B*, inclined to the axis. Accordingly, it is *this straight line A–B* itself which represents the eight determinations made by Mr. Weber. Only in case the line *A–B* were parallel to the axis of weights taken (horizontal in the drawing) and if, at the same time, all deviations were small, could the point *C* be taken as a legitimate mean.

It is readily seen that the line *AB* is the geometrical representation of the equation

$$r = 57.7 - 0.113w, \qquad (1)$$

where *r* is expressed in units of the fifth place of decimals and *w* in grammes of bromine taken. That is: *r* is *not* a constant, but varies according to the form $k - cw$, where *k* and *c* are constants,

We may express the strange fact revealed in the above by saying that the result of the experiment depends on the choice of the weights taken by the chemist, so much so that "we can tell as soon as the weight has been taken and before the experiment has been

[6] It may be noted that of the two isolated determinations 7 and 5, the first (7) is made with the smallest weight of bromine and therefore shows the greatest deviation, while the last (5) made with the greatest weight of bromine falls distinctly close to the line *AB*.

made, what the outcome thereof will be," or perhaps more strikingly still, we might say that "we get (within sufficiently large limits to count) whatever value r we would like to get."

But the value of r directly determines the value of the atomic weight itself, as we shall show in detail; hence the fact just stated for the ratio applies with equal force to the atomic weight itself.

IV. Systematic Errors and Chemical Perturbations.

The existence of such systematic errors in the most refined laboratory work of renowned chemists, from Stas to the present, is not a new discovery, for I have proved the existence thereof twenty years ago. See the note presented by Berthelot at the Séance of the twelfth of December, 1892.[7]

I here insert (Plate XXXVI.) a reduction to half the original scale of the diagram (no. 215) published in the note just mentioned, together with the diagram (no. 216) of the next note (February 27, 1893). The new cut (no. 752) is a like reduction of Plate I. of my "True Atomic Weights" of 1894 and represents the systematic errors of Stas in his famous syntheses of silver nitrate (no. 251) and of lead nitrate (no. 252). See plate XXXV.

Indeed it is even forty years since I first pointed out the existence of definite *perturbations* (or disturbances) in the chemical work of Stas, namely at the Salem meeting of the American Association for the Advancement of Science in 1869,[8] of which the part here in question is reprinted in my "True Atomic Weights," 1894, pp. 65–69, under the regretfully appropriate heading: vox clamantis in deserto.

We shall, however, in the future restrict the term "chemical perturbation" to such systematic errors as are expressible by a definite function and therefore representable by a definite curve. Such are the systematic errors in the recent work of Mr. Weber, being represented analytically by an equation of the first degree (1) and geometrically by the straight line A–B (cut no. 750, Plate XXXIV.).

[7] *Comptes Rendus*, T. 115, p. 1074.

[8] *Proceedings*, pp. 112–124.

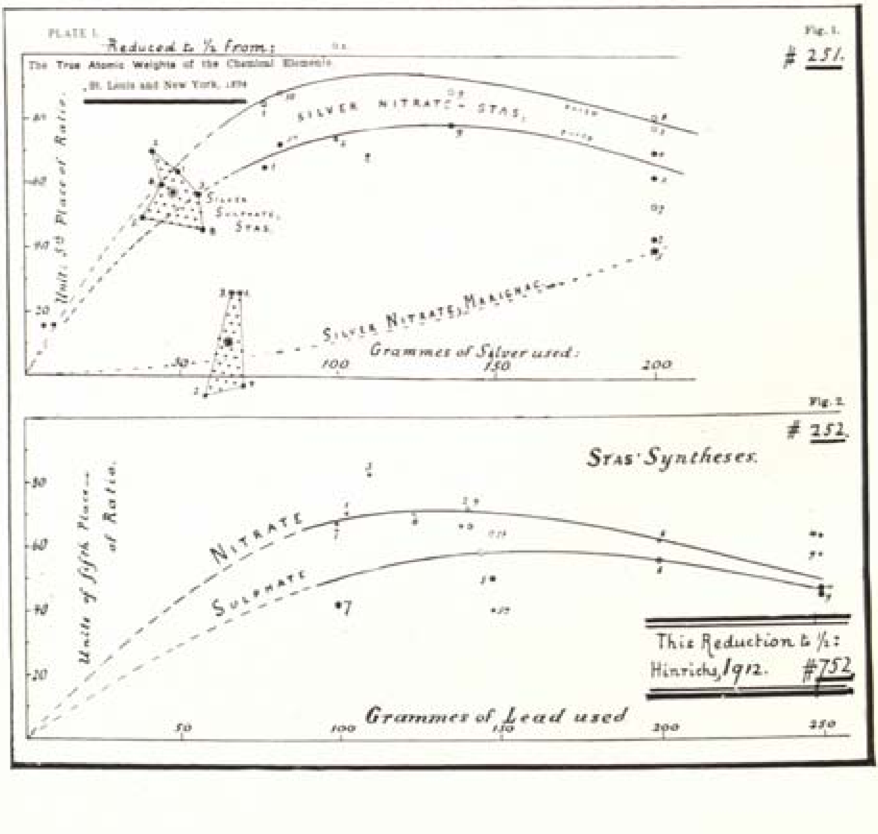
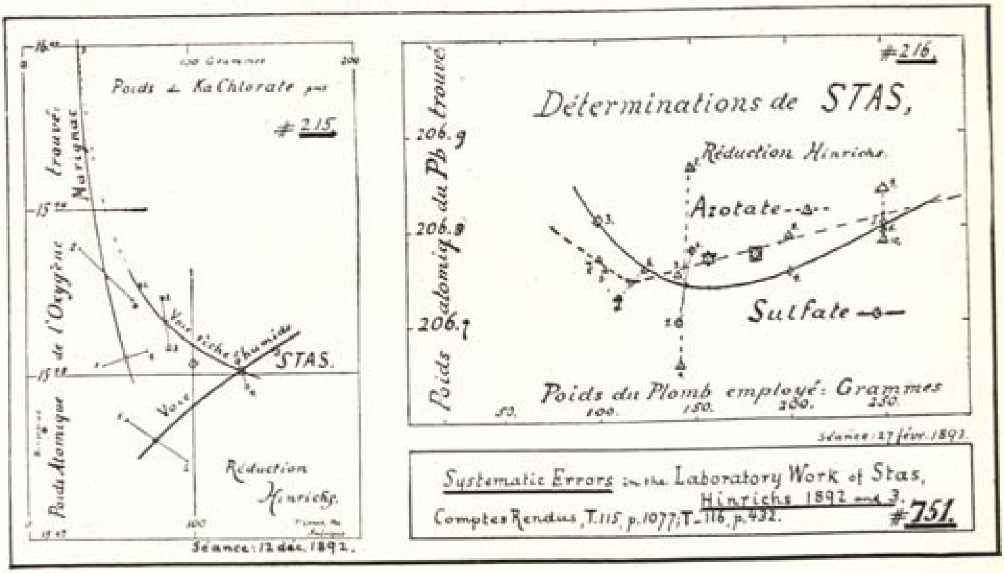


PLATE I.
Reduced to ½ from:
The True Atomic Weights of the Chemical Elements
St. Louis and New York, 1894
Fig. 1.
251.
SILVER NITRATE - STAS.
Silver Sulphate, Stas.
Units of 5th Place of Ratio.
Silver Nitrate, Marignac.
Grammes of Silver used:
50
100
150
200
Fig. 2.
252.
Stas' Syntheses.
Units of fifth Place of Ratio.
Nitrate
Sulphate
This Reduction to ½:
Hinrichs, 1912.
#752.
Grammes of Lead used
50
100
150
200
250


Poids de Ka Chlorate
#215
Poids Atomique de l'Oxygène trouvé
Marignac
STAS.
Réduction Hinrichs
Séance: 12 déc. 1892.
#216.
Déterminations de STAS,
Réduction Hinrichs.
Azotate
Sulfate
Poids atomiq. du Pb trouvé
206.9
206.8
206.7
Poids du Plomb employé: Grammes
100.
150.
200.
250.
Séance: 27 févr. 1893.
Systematic Errors in the Laboratory Work of Stas,
Hinrichs 1892 and 3.
Comptes Rendus, T.115, p.1077; T.116, p.432.
#751.

In fact I have communicated to prominent chemists in the United States and in France first proofs of some of my new cuts representing quite a number of such chemical perturbations. All the dominant elements[9] and a number of the others have now been so represented. These first proofs form already quite an atlas. One of these cuts (no. 737) has been published in the *Comptes Rendus* of the meeting of May 6, 1912.[10] It covers work of Richards at Harvard and of Guye at Geneva, on the dominant elements Ag, Cl and N, O, respectively.

By this work we have also introduced into chemistry the method of demonstration of the geometricians of ancient Greece known as the "*reductio ad absurdum,*" which is just as decisive in modern chemistry of precision as in geometry, the highest science of ancient Greece.

V. The Rational Method of Reduction.

This was first published in the *Comptes Rendus* of March 27, 1893 and in my "True Atomic Weights" of 1894. It has been extended and perfected during twenty years, but no complete exposition of all the steps involved having been published in one place at one time, it is no doubt somewhat difficult to grasp and use the same. It is for this reason that we here give, *merely as an example,* its application to the laboratory work of Mr. Weber on bromine.

The old way of successive substitution, producing of necessity an accumulation of errors unknown in magnitude, is based upon the elementary method of solving an algebraic equation with supposedly one unknown only, when in fact it contains as many unknown as there are elements present in the chemical reaction employed. Since, however, in a chemical reaction it is impossible to accept any one element as without error in its action, all these equations are de facto indeterminate (or diophantic) and therefore insoluble. The solutions given by the school are therefore erroneous and cannot be in accord with the facts.

But while the work of the school during the entire century has thus necessarily failed to give a true solution of the problem by that

[9] *Comptes Rendus,* T. 153, p. 817; 30 Oct., 1911.

[10] T. 154, p. 1228.

method, it has established incidentally one general fact of great practical importance, namely that all the atomic weights are approximations to certain whole or half numbers, if the atomic weight of oxygen is taken at 16 exactly.

Consequently we may say that the entire mathematical problem will require only the exact determination of the value of this small *departure* (which we now represent by the Greek letter epsilon ϵ).

Every mathematician knows that all relations, even the most complex, are thereby reduced to simple proportions. Hence all our calculations can be carried out by proportional parts, if the necessary relations have first been deduced either by geometry or by development into series. We have used both methods. After overcoming these difficulties we have systematized the work by simple analytical processes, retaining however the general geometrical method for the presentation of the data of experiment and the results of calculation, as exemplified above and in our numerous diagrams of which reductions by photography are printed.

It seems best, at this point, to state the degree of precision aimed at: the third decimal (thousandths) of the atomic weight and the fifth decimal (hundred thousandths) of the ratios (atomic R and analytic r). If at any time we feel authorized to go beyond this general limit, the higher decimals are given as decimals to the above, in order to conform to definitions given and to avoid confusion.

VI. The Departure, ϵ.

The true atomic weight of bromine is known to be some value quite near the number 80; all chemists admit this as an established fact. *Hence we limit our work to the determination of the precise small number of thousandths of the unit, our departure* ϵ.

Accordingly we say: the exact atomic weight of bromine is $80 + \epsilon$. We then perform all analytical operations with this sum instead of using the one symbol Br. Thus many terms will cancel and others will drop out as minute quantities of too high an order to be of influence on the result: facts and processes familiar to all those versed in mathematical work. In this way we finally obtain readily workable formulæ. (See p. 61 of our "Cinquantenaire,"

1910, for an example and note the interesting story of its wanderings in 1907 and 1908.) This may be sufficient for the present to direct those readers who may need such reference.

We now return to the simple practical details necessary for carrying out the work of determining the small departure ϵ for bromine.

VII. The Atomic Ratio *R*, and its Variation Δ

To express the chemical reaction used, we first take the departure as zero (that is Br = 80 exactly and H = 1.008 to the nearest thousandth), as we have shown it to be in our history of all determinations for hydrogen made in the century past.[11] This gives us R and Δ as shown in Table III. by elementary mathematics.

TABLE III.

Ratio for	1st H/Br		2nd H/HBr		3rd Br/HBr	
First, for	Br = 80		and		H = 1.008	
Atomic ratio	$\frac{1.008}{80}$		$\frac{1.008}{81.008}$		$\frac{80}{81.008}$	
which is $R =$	0.012	60.1	0.012	44.4	0.987	55.7
Second, for	Br = 80.1		and		H = 1.008	
Atomic ratio	$\frac{1.008}{80.1}$		$\frac{1.008}{81.108}$		$\frac{80.1}{81.108}$	
which is $R' =$	0.012	58.5	0.012	42.9	0.987	57.2
hence $\Delta Br = R' - R =$	−1.6		−1.5		+1.5	
Third, for	Br = 80		and		H = 1.108	
Atomic ratio	$\frac{1.108}{80}$		$\frac{1.108}{81.108}$		$\frac{80.0}{81.108}$	
which is $R'' =$	0.013	85.1	0.013	66.2	0.986	33.9
hence $\Delta H = R'' - R$ is	125.0		121.8		−121.8	

[11] *Revue gén. de Chimie,* 1910, 377–389.

VIII. The Analytical Excess e.

This is the number of units of the fifth decimal by which r exceeds R; that is

$$e = r - R. \tag{2}$$

Table II. gives the following results:

TABLE IV.

Values of the Analytical Excess, e.

No. $R =$	W Br (grammes) ……	1 H/Br 0.012 60.1	2 H/HBr 0.012 44.4	3 Br/HBr 0.987 55.7
1	61.3	1.1	1.2	0.1
2	68.3	0.8	0.8	0.6
3	61.4	0.9	0.9	1.4
4	76.9	0.6	0.7	−0.6
5	85.3	0.8	0.8	−0.7
6	79.1	0.7	0.7	0.5
7	59.5	0.9	0.8	−5.1
8	77.9	0.7	0.7	−1.4
9	79.4	1.0	1.0	0.1
10	65.0	0.7	0.8	3.0
Mean	71.4	0.8	0.8	−0.2

The concordance between r (experiment) and R (absolute value) is almost perfect, $e = r - R$ affecting the millionths almost exclusively (in all but four of the thirty cases!).

If we were to decide by mean values, in accordance with the common practice of the school, we would have to conclude that *the true atomic weight of bromine is 80 exactly;* for the mean analytical excess is only 8 millionths above in the first and second ratios and merely 2 millionths below in the third ratio. This implies a truly marvelous approximation to our absolute atomic weight Br = 80 exactly.

Since the third ratio is mathematically the sharpest, being near unity, we might claim in truth having demonstrated with "astronomical precision" that the atomic weight of bromine is 80 exactly.

By means of the known value of the variation Δ we can readily convert the value of the analytical excess into the corresponding departure ϵ in thousandths of the unit of atomic weights.

IX. The Variation of the Analytical Excess, e.

The mere fact that the mean value of the excess e is very small (0.2 only) is, however, not sufficient to completely establish the conclusion just drawn, as we have always accentuated; for some of the individual values of the excesses might be large with opposite sign, or show notable *systematic variations*—this they do in fact in the present case.

Hence it is necessary to study the individual values of the analytical excess for each laboratory determination made. They are given in Table IV. of section VIII., in the last column. By simply drawing (on diagram no. 750) the base line (horizontally) through the point on the scale of the analytical ratios for the value of the atomic ratio, $R = 0.98755.7$ (see VII.), we get the representation of e on the diagram. This horizontal line is shown on our cut no. 750, which thus exhibits the exact value of the analytical excess for every individual determination made. See Plate XXXIV.

Taking this line as the new axis of abscissæ for e the equation of the line of perturbation will be

$$e = 0.113(75 - w). \qquad (3)$$

It is not necessary to discuss this equation, since it corresponds exactly to that for r already considered in III.

X. The Increment, Σ.

Σ is the change in the third decimal of the atomic weight produced by one unit in the fifth place of the analytical ratio r.

It will be impossible to enter here upon the complete deduction of the formulæ now to be presented for practical work; for our deduction we must refer to a series of papers in the *Comptes Rendus* from 1907 to the present and to our publications in other quarters, especially including the facsimile of a general deduction which has travelled between Paris and St. Louis in 1907 and again in 1908; see p. 61 of my "Cinquantenaire de L'atomécanique, 1910," under the title: Un Manuscrit Voyageur. All these more recent develop-

ments of general formulæ really go back to 1894 in my "The Atomic Weights," pp. 157–161. On p. 159 will be found the formula (42) for the chemical perturbation, essentially the same as the one we have been using for a number of years.

In fact, it would be interesting to trace the development we have been able to make of the method of Lagrange so renowned with mathematicians and astronomers under the name of "The Method of the Variation of the Arbitrary Constants."

Our simplest formula, obtained by means of Taylor's most general formula, for m chemical elements present in the reaction, is

$$\Sigma\epsilon\Delta = 100e. \qquad (4)$$

Treating the effect of the elements ex-æquo, this equation becomes

$$m\epsilon\Delta = 100e, \qquad (5)$$

or simply

$$\epsilon = \Sigma e; \qquad (6)$$

if we introduce the increment Σ as defined above

$$\Sigma = 100/m\Delta, \qquad (7)$$

which also may be defined as the departure per unit of the excess e.

In the case under consideration we have the variation determined in VIII., while the number of elements present (m) is 2 (Br and H); hence the third reaction (the sharpest) gives the values of the departures presented in the next section XI. as Table V.

XI. Summary of Results Obtained for the Reaction $R = Br : HBr$.

TABLE V.

I. The Arbitrary Constants a (*i. e.*, the Absolute Atomic Weight) and their Variation (Δ, Σ).

	Elements Br	Elements H
Absolute atomic weight, a	80	•1.008
Variation, Δ (units of fifth place)	1.5	—121.8
Increment, Σ (units of third place)	33⅓	— 0.41
Departure, ϵ, by e	33⅓e	— 0.41e

II.—Mean Values of Departures, ϵ.

Point	Experiments	w	e	eBr	eH
A	1, 2, 3, 10	64.0	1.25	41.5	—0.51
B	4, 6, 8, 9	78.3	—0.35	—11.7	0.14
		Mean of groups A and B.			
C	*A, B*	71.61	0.45	15.0	—0.18
		Mean of all Determinations.			
D	*C, d*	71.77	—0.22	— 7.3	0.09
Departure as function of $w' = 75 - w$				$3.77w'$	$-0.05w'$

III.—Mean Atomic Weights.

Point	Experiments	w	e	Br	H
A	1, 2, 3, 10	64.0	1.25	80.042	1.0075
B	4, 6, 8, 9	78.3	—0.35	79.988	1.0081
		General Means.			
The 2 groups of four determinations each:					
C	*A, B*	71.61	0.45	80.015	1.0078
All ten determinations:					
D	*C, d*	71.77	—0.22	79.993	1.0081

IV.—True Atomic Weight.

For all possible weights, *i. e.* entire line:

Point	Experiments	w	e	Br	H
A—B	1,2,3,4,6,8,9,10	71.61	0.00	80.000	1.0080

Note.—Confirmatory determinations desirable especially for weights symmetrically taken in reference to *A* and *B;* that is for mean weights of about 86 and 72 grammes.

Reference: "True Atomic Weights," 1894, p. 158.

XII. General Conclusion.

It will have been noticed that our work really gives *three* distinct demonstrations that the atomic weight of Bromium is 80 exactly.

First (as shown above in VIII.), by the *limit-method,* the means closely approaching the value Br = 80 exactly.

This method was first published in the *Comptes Rendus* from 1892 to 1894 when it was more fully developed in my book: "The True Atomic Weights," 1894, of which Berthelot accepted the dedication.

Second. By the "Chemical Perturbations," representing all determinations by a single straight line, intersecting the axis of abscissæ of weights taken.

This also demonstrates completely that the true atomic weights *cannot* be determined by empirical methods alone.

In fact, the empirical methods lead really more and more away from the truth by the chemists trying to secure greater concordance —which can most easily be reached by limiting the range of weights taken (as already shown here) and in many other ways, all leading into error. We hope soon to take up this most important practical subject more thoroughly.

Third.—By the *reductio ad absurdum,* showing that the atomic weight for the individual determination is de facto a function of the weight taken for effecting the determination; this result is evidently absurd, because the atomic weight in its very nature is independent of the amount or weight of the substance operated upon.

In other words: the individual determinations establish the line of perturbation only, the intersection of which with the axis of weights taken (for $e = 0$) gives the true solution for all experiments represented on that line of perturbations.

Final Conclusion. While each one of these three demonstrations, taken separately, is sufficient to prove that the true atomic weight of bromine is 80 exactly, they properly constitute three consecutive steps in *one complete demonstration* which itself has been gradually developed in that order above given. It may be best to repeat them here as links of that chain of demonstration:

1. The values of the analytical excess e are minute and of opposite sign, giving a mean more or less closely approaching to zero; hence the horizontal line $e = 0$, determined theoretically by the atomic ratio R, is the locus of the true atomic weight.

2. The straight line of perturbation is a second locus of the same; *hence the intersection of these two lines determines the weight for which the laboratory work is without error.*

3. The other parts of the line of perturbation give the atomic weight as function of the weight taken for the experiment, which being absurd, proves that they only serve to determine the point

of intersection, as just done. Besides: each single point in the line of perturbation *above* the point of intersection is balanced by the equal value of contrary sign *below* that line symmetrical with the above point.

Trusting that we have made this subject as clear as so difficult a matter—at first reading—may be made, we shall add only that all thought of the so-called "probable error" of the mean must be laid aside in atomic weight determinations; we have repeatedly shown its utter absurdity in this field—the more careful laboratory work having the desperate character of placing itself squarely far beyond the field restricted for it by the so-called "probable error of the mean" so as to leave it not a shred of probability. We expect as soon as possible, by a most striking example (covering all the work done for an important element) to show the utter fallacy of this "probable error of the mean" introduced by Gauss a century ago. We shall, at the same time, show that it is but a false and misleading substitute for the simple mean value of the actual distance of each determination from the mean of all.

We here insert, from a most extended table carefully classified by order of magnitude and for each individual element separately, giving the most general results in a broader grouping, to show the fact referred to above: that with progress in practical laboratory work, the final departure has been greatly reduced.

The four catalogues of work represent: (*A*) recent and classical work (Dumas, Stas to present); (*B*) older determinations (except the classical); (*C*) dominant elements only: *i. e.*, O, Cl, Ag; C, Na; S, Br, H; N, Ka.

PER CENT. OF EACH GRADE SPECIFIED.

Grade in Words	ϵ	Catalogue				
		B	AB	A	C	
Excellent to good	Below 100	77	85	93	98	per 100
Poor to bad	Above 100	23	15	7	2	per 100

Number of:				
Determinations	508	967	459	159
Reactions	163	340	177	53

PROCEEDINGS

OF THE

AMERICAN PHILOSOPHICAL SOCIETY

HELD AT PHILADELPHIA

FOR PROMOTING USEFUL KNOWLEDGE

VOL. LII — NOVEMBER–DECEMBER, 1913 — No. 212

THE MARINE TERTIARY STRATIGRAPHY OF THE NORTH PACIFIC COAST OF AMERICA.

BY RALPH ARNOLD AND HAROLD HANNIBAL.

(PLATES XXXVII–XLVIII.)

COLUMNAR SECTION OF THE COLUMBIA RIVER AND SHOALWATER BAY DISTRICT.

	Pleistocene marine terraces, 50′
	Pliocene basalt
	Monterey formation, 400′
Astoria Series	*Seattle formation* tuffaceous shales and sandstone with interbedded basalts of Nazel, Grays River, Ilwaco, and Astoria. 5,000′
Astoria Series	*San Lorenzo formation* tuffaceous sandstones and shales with interbedded basalts of Winlock, Pe Ell, Holcomb, Clatskanie, and Scapoose. 10,000′
Tejon Series	*Olequa formation* tuffaceous lignitic sandstones of Little Falls and Coal Creek above Stella. 3,000′
Tejon Series	*Chehalis formation* tuffaceous lignitic sandstones and shales of marine and estuarine origin east of Winlock and in the upper Cowlitz Basin. 10,000′
	Bedrock complex

Columnar Section of Willamette Valley and Upper Umpqua Basin.

Pliocene basalt	
Astoria Series	*San Lorenzo* tuffs of Silverton and Eugene. 1,000′
Tejon Series	*Arago formation* tuffaceous and arkose sandstone of Umpqua Basin, coarse basic tuffs farther north on Santiam River. 10,000′
Bedrock complex	

Columnar Section of the Coast Range and Coast of Oregon.

Marine Pleistocene terraces, 50′	
Elk River formation, 300′	
Merced formation, 50′	
Empire formation, 500′	
Monterey formation sandstone and clay shale of Newport. 2,000′	
Astoria Series	*Seattle formation* tuffaceous sandstone and shale of Nehalem and Yaquina Bays. 5,000′
Astoria Series	*San Lorenzo formation* tuffaceous sandstone and shale of Upper Nehalem and Yaquina Rivers. 5,000′
Tejon Series	*Arago formation* tuffaceous lignitic sandstones and shales of Coos Bay district becoming more and more tuffaceous to north and grading into coarse tuffs and basaltic flows of Wilson River and South Nehalem River. 10,000′
Bedrock complex	

COLUMNAR SECTION OF THE GRAYS HARBOR AND CHEHALIS VALLEY DISTRICT.

Series	Formation
	Admiralty till
	Empire formation sandstones and tuffaceous shales with basalt tuffs at base, west and north of Chehalis Valley. 4,000′
	Monterey formation sandstones and clay shales south of Chehalis Valley. 4,000′
Astoria Series	*Seattle formation* tuffaceous s.s. and sh. of Delazine Cr. 1,600′
Astoria Series	*San Lorenzo formation* tuffaceous sandstone and shale at Lincoln Creek and north of Oakville, Porter, and Elma with basalts at base. 3,000′
Tejon Series	*Chehalis formation* tuffaceous lignitic sandstones and shales, marine and estuarine with interbedded basic flows and tuffs at Chehalis and the Balch syncline. 9,000′
	Bedrock complex

COLUMNAR SECTION OF PUGET SOUND AND THE SAN JUAN ISLANDS.

Series	Formation
	Saanich formation, 50′
	Vashon drift
	Admiralty till
Astoria Series	*Seattle formation* conglomerates and tuffaceous sandstones and shales of the Seattle monocline. 4,000′
Astoria Series	*San Lorenzo formation* tuffaceous sandstones and shales with basalts and andesites at base, of Bean Point and Port Townsend. 5,000′
Tejon Series	*Olequa formation* tuffaceous lignitic sandstones and shales of marine and estuarine origin forming the coal series of Whatcom County and the upper 12,000′ of the Pierce County section.
Tejon Series	*Chehalis formation* tuffaceous lignitic sandstones and shales of marine and estuarine origin of Fairfax and the Pierce County coal field. 5,000′
	Bedrock complex

COLUMNAR SECTION OF THE STRAITS OF FUCA AND WEST COAST OF THE OLYMPIC PENINSULA.

Admiralty till

Merced formation, 400′

Empire formation
sandstones of Bogochiel River, tuffaceous shale of Taholah.
1,600′

Monterey formation
lignitic sandstone of Clallam Bay section.
2,000′

Astoria Series

Twin River formation
clay shales of Twin River section.
2,000′

Seattle formation
tuffaceous shale and sandstone of Sekin River and Gettysburg.
3,000′

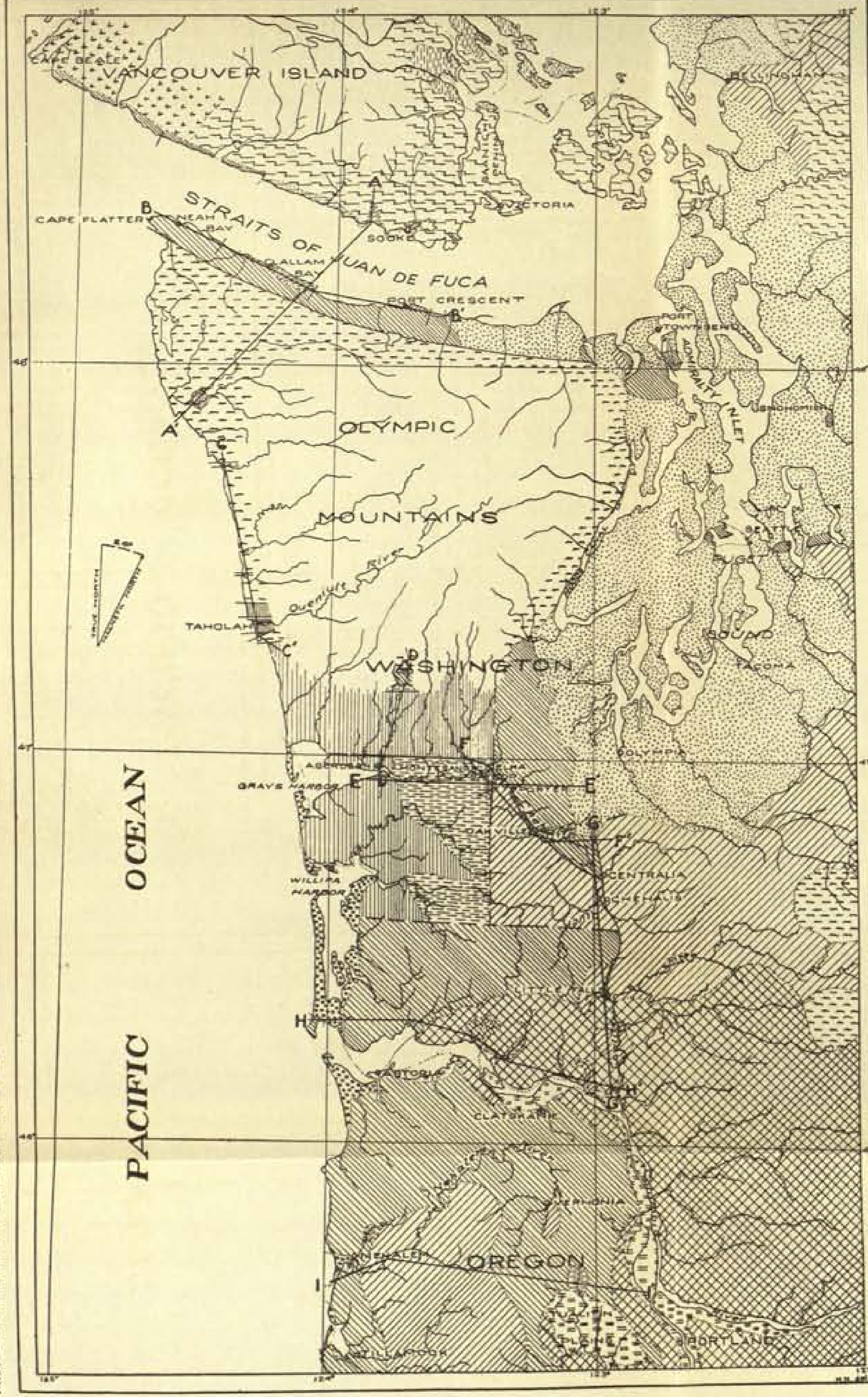
San Lorenzo formation
tuffaceous shale and sandstone of southwest coast of Vancouver Island, heavy conglomerates of the Cape Flattery section.
17,000′

Sooke formation
sandstones and conglomerates of Muir Creek.
1,600′

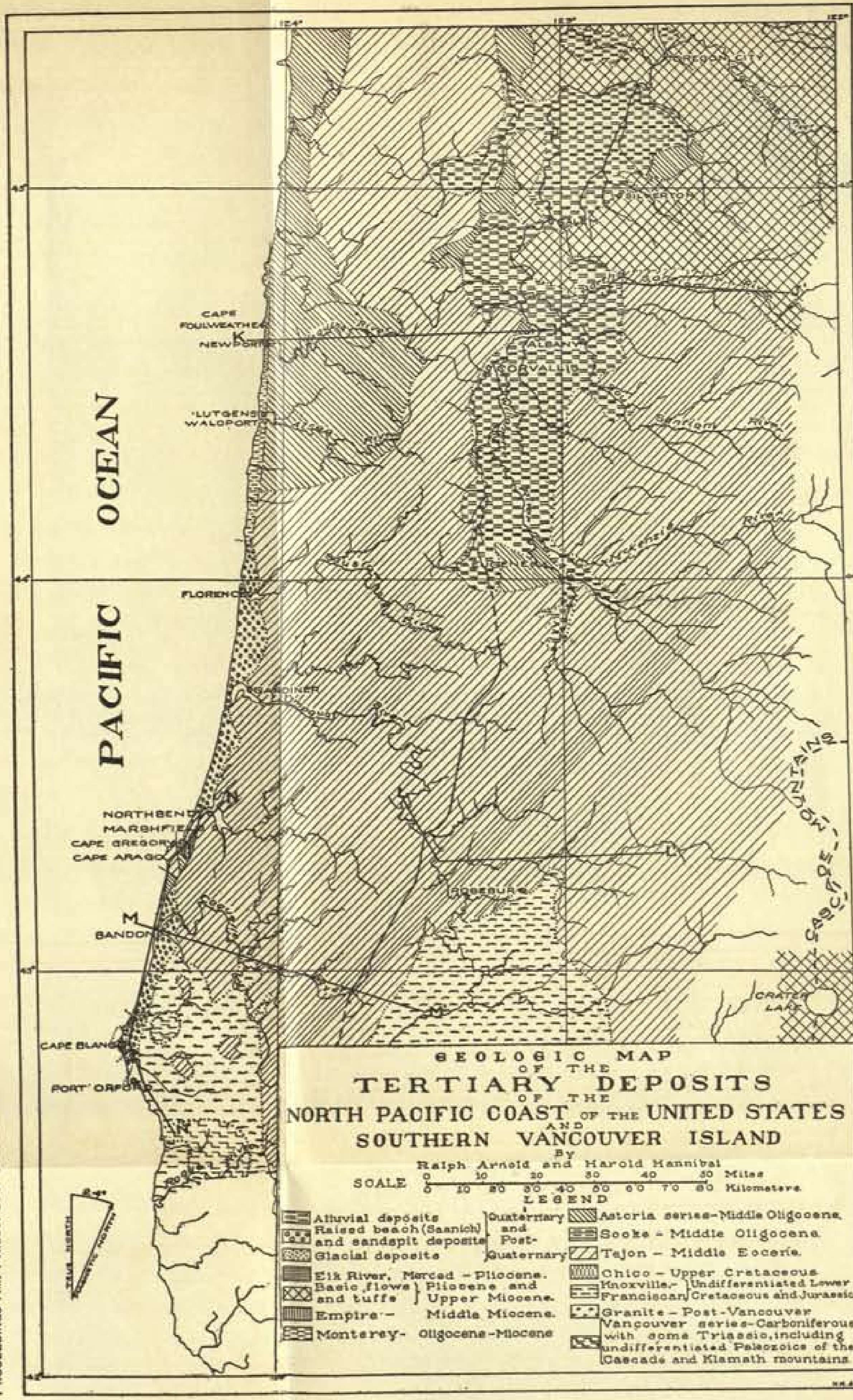
Tejon Series

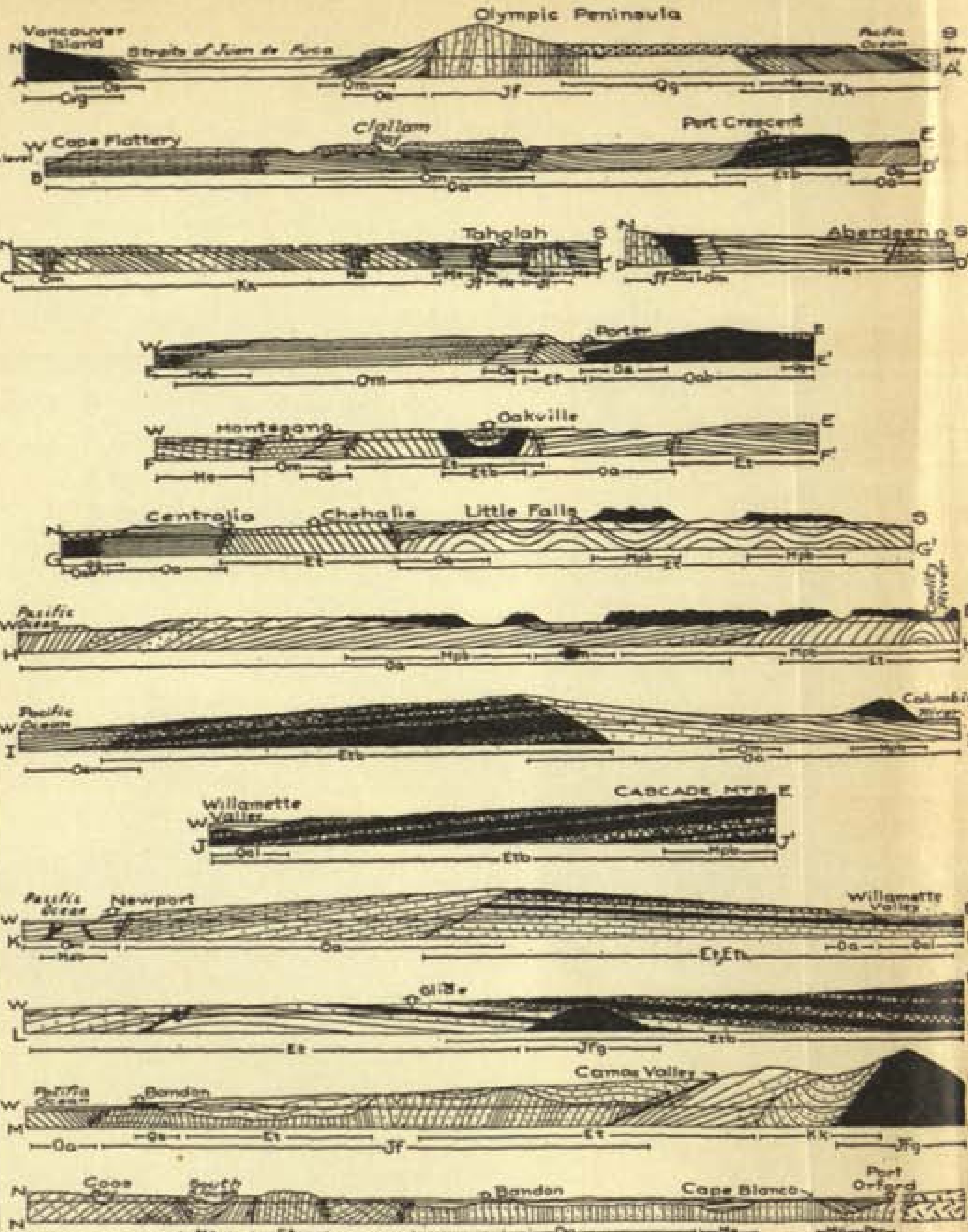
Arago formation
basalt tuffs of Port Crescent and west of Discovery Harbor.
3,000′

Bedrock complex



Geologic Map of the Tertiary Deposits of the North Pacific Coast of the United States and Southern Vancouver Island. For explanatory symbols see Plate XXXVIII.

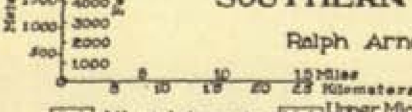




GEOLOGIC SECTIONS OF THE TERTIARY DEPOSITS OF THE NORTH PACIFIC COAST OF THE UNITED STATES AND SOUTHERN VANCOUVER ISLAND

BY

Ralph Arnold and Harold Hannibal



LEGEND

Qal Alluvial deposits	Mpb Upper Miocene and Pliocene basalts	Oab Astoria basalts	Jfg Franciscan greenstones and serpentine
Qs Raised beach deposits	Me Empire	Os Sooke	Jf Franciscan
Qg Glacial deposits	Mb Empire basalts	Et Tejon	Cvg Vancouver greenstones
Per Elk River	Om Monterey	Etb Tejon basalts	C Colebrook schist
Pm Merced	Oa Astoria	Kk Knoxville	

PROCEEDINGS AM. PHILOS. SOC. VOL. LII, NO. 212

General Remarks.

The recognition of marine tertiary on the North Pacific Coast of America dates back to 1848 when Conrad[1] described several fossil mollusca from "the tertiary deposits on the Columbia River near Astoria." More recent studies by Richardson, Condon, Diller, Willis and Smith, the senior author, and other writers too numerous to mention have shown that such rocks underlie all of Oregon west of the Cascade Range and north of the Klamath-Siskiyou Mountains, western Washington except the Olympic Range, and portions of Vancouver Island. The several geological horizons have in most instances been named and something is known of their fossil contents but their stratigraphic relations one to another and their correlatives among the closely related formations of California are scarcely understood.

Several years ago the senior writer visited the more important fossil localities then known in western Oregon and Washington in the interests of the United States Geological Survey. No general report of the work was published owing to the necessity of further field studies but descriptions of the stratigraphy of particular districts are to be found in "Gold Placers of the northwestern coast of Washington,"[2] "Coal in Clallam County, Washington"[3] and "A Geological Reconnaissance of the Olympic Peninsula."[4] Some of the palæontological material obtained was described in "The Tertiary and Quaternary Pectens of California,"[5] "Descriptions of New Cretaceous and Tertiary Fossils from the Santa Cruz Mountains, California"[6] and "The Miocene of Astoria and Coos Bay, Oregon."[7] The distribution of land and water in this region during the different tertiary periods is treated of in a preliminary way in "Environment of the Tertiary Faunas of the Pacific Coast of the United States."[8]

1 *Amer. Jl. Sci.*, 2d series, V., 1848, p. 432.

2 Arnold, R., Bull. 260, U. S. Geol. Sur., 1905, p. 154–7, Fig. 11.

3 Ibid., p. 413–421.

4 Arnold, R., *Bull. Geol. Soc. Am.*, XVII., 1906, p. 451–468, Pl. 55–58.

5 Arnold, R., Prof. Pap. 47, U. S. Geol. Sur., 1906, 264 pp., 53 Pl.

6 Arnold, R., Proc. U. S. Nat. Mus., XXXIV., 1908, p. 345–390, Pl. XXXI.–XXXVII.

7 Dall, W. H., Prof. Pap. 59, U. S. Geol. Sur., 1909, 284 pp., 23 Pl.

8 Arnold, R., *Jour. of Geol.*, XVII., 1909, p. 509–533.

In 1911 the junior writer was commissioned to continue the exploration at private expense and the months of June, July, and August were spent in examining the various described sections and districts of the Oregon coast and western Washington. With the opening of the spring of 1912 as opportunity offered, short trips were undertaken from Seattle to points about Puget Sound and the Straits of Fuca, and three weeks were spent on the southwest coast of Vancouver Isand. In June extended field work was resumed and a trip made from Port Townsend west to Cape Flattery along the north coast of Washington, following which two months were spent in southwestern Washington. Six weeks more were given over to further collecting in western Oregon, field work being concluded in October.

The present paper, preliminary to more extended accounts of the stratigraphy and palaeontology, is based primarily on the work done in 1911 and 1912. The faunas listed here include described species obtained at, or in the vicinity of, the several type sections or, if the deposits are referred to formations described first from California, characteristic faunas from some district on the North Pacific Coast in lieu.

Bedrock Complex.

The bedrock complex on which the marine tertiary deposits were laid down varies widely from place to place.

In southern Oregon the underlying rocks are chiefly Mesozoic, the Franciscan (Myrtle in part), Dothan, and Galice formations of Jurassic age, and the Knoxville (Myrtle in part), Horsetown, and perhaps also Chico formations which are Cretaceous (the Knoxville may extend into Jurassic). These have been partially described by Diller[9] and Londerback[10] though much work still needs to be done to elucidate the complicated stratigraphy.

In the Olympic Mountains the Tertiary rests indiscriminately

[9] Roseburg Folio, No. 49, U. S. Geol. Sur., 1898; Port Orford Folio, No. 89, U. S. Geol. Sur., 1903; Mesozoic Sediments of Southwestern Oregon, *Am. Jour. Sci.*, XXIII., 1907, p. 401–421; "Strata containing the Jurassic Flora of Oregon," *Bull. Geol. Soc. Am.*, XIX., 1908, p. 367–402.

[10] "The Mesozoic of Southwestern Oregon," *Jour. of Geol.*, XIII., 1905, p. 514–555.

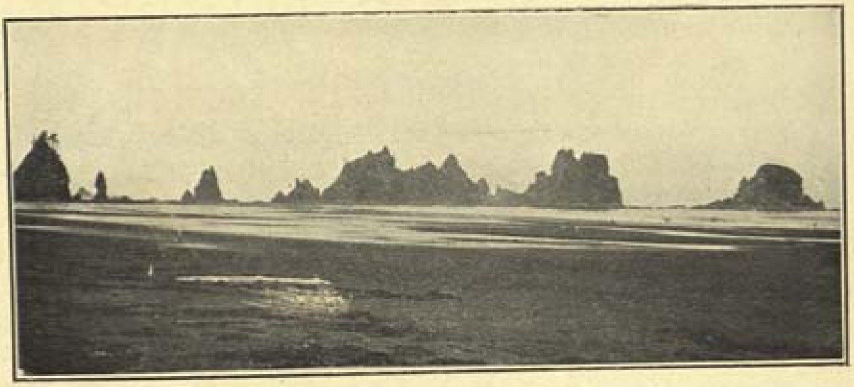


FIG. A.

FIG. B.

FIG. A. Point of the Arches from Shi Shi Beach near Neah Bay, Washington. A characteristic exposure of Franciscan rocks such as form the Olympic complex.

FIG. B. Diabase flow intercalated in Arago beds (Tejon series) on Umpqua River near Glide, Oregon.

upon indurated shales, sandstones, and conglomerates of supposed Cretaceous age[11] and a great complex of metamorphic sandstone, shale, radiolarian chert, glaucophane schist, and greenstones cut by peridotite serpentine, a series closely resembling the Franciscan of southern Oregon and the California Coast Ranges.

In the Cascade Mountains of Oregon and southern Washington the contacts between the tertiary and older rocks are usually obscured by outpourings of lava but farther north Russell[12] has described Mesozoic and older sediments associated with granite, greenstones and serpentine.

On Vancouver Island the Vancouver Series underlies the Oligocene; it is composed of slates, limestones, and greenstone-diorites of supposed Carboniferous and perhaps also Triassic age, cut by biotite granite. This has been described by George M. Dawson.[13] Farther north in the Straits of Georgia Chico rocks have a wide distribution.

Eocene Deposits—The Tejon Series.

Eocene deposits form a large proportion and from an economic standpoint the most important part of the Tertiary sediments of western Oregon and Washington. These belong so far as known exclusively to the Tejon Series. Everywhere that a contact has been observed the Tejon lies directly on the pre-tertiary rocks, so it appears that the Martinez formation (early Eocene) of California is not represented on the north Pacific coast. In addition to being the most widespread formation the Tejon is the most extensively developed. Prevailing low dips render it impossible to study it conveniently in any one section, but from data obtained in the coal field of Pierce County, Washington, and several other partial sections it is probable that 15,000 feet is not too great an estimate of the thickness of the series in western Washington, while in Oregon at least 13,000 feet of beds stratigraphically higher are present. This

[11] Arnold, R., *Bull. Geol. Soc. Am.*, XVIII., 1906, p. 459.

[12] "A Preliminary Paper on the Geology of the Cascade Mountains in Northern Washington," 20th Ann. Rept. U. S. Geol. Sur. (II), 1900, p. 83–210.

[13] 2d Ann. Rept. Geol. Sur. Can., 1887, p. 10*B*–13*B*.

extraordinary development of sediments is only to be explained by a consideration of the nature of the deposits. These are at some points coarse basalt tuffs and at others, and by all odds this is the most prevalent type of sedimentation, worked over volcanic ejectmenta in the form of sandstones or shales deposited under estuarine conditions, evidently with considerable rapidity.

Three divisions, the Chehalis, Olequa, and Arago formations, represent well-marked palæontological horizons that can be recognized by characteristic faunas and floras over the North Pacific Coast. The latter is not found in juxtaposition with the Chehalis and Olequa and may represent a later phase of the Eocene equivalent to the Ione of California.

Faunal Divisions of the Tejon Series.

Tejon Series	Arago formation—zone of *Venericardia horni* variety with obsolete ribs		Tropical flora—fan-palms, magnolias, figs, and ferns.
	Olequa formation	zone of *Venericardia horni* Gabb[14]	Austral flora—birches, sycamores and chestnuts.
	Chehalis formation		

The Chehalis and Olequa formations usually consist of fine material and are essentially estuarine deposits throughout, containing numerous lignite beds interstratified with alternating fresh water and marine sediments. The Arago of the Coos Bay-Port Orford coal fields is similar but commonly consists of coarser material partly arkose in character. Farther north in Oregon this horizon is represented by basic flows and coarse bedded tuffs occasionally carrying marine fossils. In the Roseburg district it is essentially tuffaceous sandstone of marine origin. Coarse basalt tuffs carrying marine fossils and interbedded with basic flows and a subordinate amount of sandstone on the north coast of Washington are also referred to this horizon on the basis of palaeontological evidence.

[14] Usually cited as *V. planicosta* Lam., but the real *planicosta* is confined to the Martinez formation on the Pacific Coast.

Table of Correlation of the Tertiary and Quaternary Horizons of the Pacific Coast.

Age.	North Pacific Coast. Formation.		North Pacific Coast. Chief Zone Fossils.	California. Formation.	California. Chief Zone Fossils.
Pleistocene				Upper San Pedro	
				Lower San Pedro	
	Saanich				
	Vashon Drift				
	Admiralty Till				
Pliocene	Elk River		*Cardium corbis* Mart. *Scutella oregonensis* Clark *Turris smithi* Arn.	Deadman Island (Santa Barbara Pliocene)	*Echinarachnius excentricus* Esch. *Turris smithi* Arn. *Turritella jewetti* Cpr.
	Merced		*Pecten dilleri* Dall *Scutella oregonensis* Clark	Merced, Purisima (in part), and Etchegoin	*Pecten healeyi* Arn. *Echinarachnius Gibbsi* Rem. *Scutella oregonensis* Clark *Scutella interlineata* Stimp
Miocene				Santa Margarita	*Astrodapsis antiselli* Conr. *Astrodapsis whitneyi* Gabb *Tamiosoma gregaria* Conr.
				Scutella gabbi–S. breweriana beds	*Astrodapsis antiselli* Conr. *Scutella gabbi* Rem. *Scutella breweriana* Gabb
	Empire		*Scutella gabbi* Rem. *Argobuccinum cammani* Dall *Mytilus middendorffi* Grnk. *Cardium coosense* Dall *Pecten coosensis* Shum. *Bullia bogachielii* Rgn.		
	Monterey (Clallam)		*Pecten propatulus* Conr. *Arca devincta* Conr. *Polinices saxea* Conr. *Venus clallamensis* Rgn. *Turritella oregonensis* Conr.	Monterey (Temblor)	*Pecten propatulus* Conr. *Arca devincta* Conr. *Ficus kernianus* Cooper *Agasoma barkerianum* Cooper *Polinices saxea* Conr.
Oligocene				Vaqueros	*Pecten magnolia* Conr. *Turritella inezana* Conr.
	Astoria	Twin River	*Acila gettysburgensis* Rgn. *Polinices olympidii* Rgn. *Turritella oregonensis* Conr.		
	Astoria	Seattle	*Acila gettysburgensis* Rgn. *Turcicula washingtoniana* Dall *Macrocallista vespertina* Conr.		
	Astoria	San Lorenzo	*Acila shumardi* Dall *Turcicula columbiana* Dall *Pecten branneri* Arn.	San Lorenzo	*Acila shumardi* Dall *Acila dalli* Arn. *Pecten branneri* Arn.
	Sooke		*Pecten branneri* Arn. *Macrocallista newcombei* Mrm. *Patella geometrica* Mrm.		
Eocene	Arago		*Venericardia horni* Gabb (obsolete ribbed variety)	Ione	*Venericardia horni* Gabb (obsolete ribbed variety)
	Tejon	Olequa	*Venericardia horni* Gabb *Pecten landesi* Arn.	Tejon	*Venericardia horni* Gabb
	Tejon	Chehalis	*Venericardia horni* Gabb *Meretrix californica* Gabb	Tejon	
				Martinez	*Venericardia planicosta* Lam *Pholadomya nasuta* Gabb

The Chehalis Formation.

The term Chehalis sandstone was used by Lawson[15] for some arenaceous bedded tuffs containing marine Eocene fossils exposed in a water tunnel through the hill east of the city of Chehalis, Washington. The beds here form an intregal part of the south limb of an anticline in which several thousand feet of conformable strata are involved, the friable nature of the rock rendering an exact estimate of the thickness difficult without instrumental measurements. The upper beds exposed by this anticline are distinctly marine while the lowest are probably of freshwater origin judging by the presence of workable coal seams.

This anticline is in turn one of a series of folds whose axes have a general east-west trend, exposed along the lower slopes of the Cascade Range east of the Portland-Tacoma railway from a few miles south of the Cowlitz River northward to Tenino. Upwards of 10,000 feet of bedded tuffaceous and lignite-bearing sandstones and shales, to a large degree of estuarine or freshwater origin, but with frequent local zones of marine fossiliferous sediments, are involved in this folding.

Other areas of the Chehalis formation are the Balch syncline west of Chehalis and Centralia, the King County coal fields extending from Allentown in the Duwamish Valley eastward and southward beneath the glacial drift to Renton, Green River, Newcastle, and Squak Mountain, and the lowest 2,000 feet of Eocene in the Pierce County coal field, the beds in which the Fairfax and Montezuma mines are located.

No equivalent strata have been recognized elsewhere in the northwest but the Tejon of the type locality near old Fort Tejon in California evidently represents the same faunal stage. In many respects the Chehalis fauna is similar to that of the succeeding Olequa formation, but the floras are markedly different, that of the Chehalis formation lacking the distinctly tropical facies of the later divisions of the Tejon, and thus affording a most characteristic feature.

[15] *Am. Geol.*, XIII., 1894, p. 437.

Excellent plant localities occur at Steel's Crossing near Allentown, the Fairfax and Montezuma mines on Carbon River, Delazine Creek near Elma, and Skookum Chuck Canon below Bucoda. The Taylor clay mine on Green River, Snoqualmie Pass, the Newcastle mine east of Lake Washington, and a point in the hills south of where the Centralia-Oakville fault crosses Lincoln Creek are also said to have contributed fossil plants belonging to this horizon.

The following marine invertebrate fauna has been obtained from the Chehalis formation.

The Olequa Formation.

Overlying the Chehalis beds is a horizon of the Tejon Series which on Olequa Creek in southern Lewis and northern Cowlitz counties, Washington, contains an excellent flora, and also marine and freshwater faunas. The type section extends from the Erwing ranch a little over two miles above Little Falls southward down Olequa Creek to Olequa, a distance of about five and one-half miles. The beds immediately below Erwing's represent a low east-west syncline in which marine beds are overlain by freshwater deposits, and these in turn by plant-bearing shales. Down the river a low anticlinal axis crosses Olequa Creek a little above Little Falls in the heart of which other freshwater and marine beds are exposed. At the railroad bridge below Little Falls the upper marine and freshwater beds reappear dipping southward and some distance above them in nearly horizontal strata appears a thin zone of coarse basalt tuff containing numerous marine fossils near the old railroad bridge above Olequa. From here southward the Eocene is mantled by Pliocene basalts associated with river gravels.

The same horizon of the Eocene reappears, however, at Castle Rock and farther west on Coal Creek above Stella in a more or less regular repetition of low folds with east-west axes. Probably the total thickness of beds in this district does not represent more than 2,000 or 3,000 feet.

The flora is noteworthy for the abundance of a large palm, probably *Calamopsis* cf. *danae* Lx. and of *Magnolia* cf. *Californica* Lx. As both these species and one or two others identical with Olequa

Partial List of Species in the Chehalis Horizon of the Tejon Series (Middle Eocene) on the Cowlitz River and Bordering the Chehalis Valley, Washington.

	57	58	113	145
PELECYPODA:				
Avicula pellucida Gabb			×	
Cardium breweri Gabb		×	×	
Corbula horni Gabb		×	×	
Crassitellites compacta Gabb			×	
Crassitellites grandis Gabb	×			
Crassitellites uvasana Conr			×	
Macrocallista conradiana Gabb		×		
Marcia quadrata Gabb			×	
Meretrix californica Conr.[16]	×			×
Meretrix horni Gabb	×	×	×	
Meretrix ovalis Gabb	×			
Meretrix uvasana Conr				×
Miltha turneri Stanton	×			
Modiolus ornatus Gabb	×	×		
Ostrea idriænsis Gabb	×	×	×	
Solen parallelus Gabb	×	×		
Tellina horni Gabb			×	
Tellina longa Gabb	×		×	
Tellina remondi Gabb	×			
Venericardia horni Gabb[16]	×	×	×	
GASTEROPODA:				
Amauropsis alveata Conr			×	
Ancillaria bretzi Wvr			×	
Calyptræa excentrica Gabb	×	×	×	
Conus remondi Gabb[16]			×	
Crepidula pileum Gabb		×	×	
Exilia diabloi Gabb[16]			×	
Ficopsis horni Gabb			×	×
Gyrineum washingtonianum Wvr			×	
Mitra washingtoniana Wvr			×	
Morio tuberculatus Gabb			×	×
Murex sopenahensis Wvr			×	
Olivella mathewsoni Gabb			×	
Perissolax washingtoniana Wvr[16]		×	×	×
Polinices horni Gabb	×	×	×	×
Polinices secta Gabb		×	×	
Pseudoliva volutæformis Gabb		×		
Rimella simplex Gabb			×	
Sinum obliquum Gabb	×	×	×	
Strepsidura whitneyi Gabb	×		×	
Thais eocenica Wvr			×	
Tritonium cowlitzense Wvr			×	
Turris fresnoensis Arn			×	
Turris io Gabb			×	
Turris sinuata Gabb[16]			×	×
Turritella uvasana Conr	×	×	×	×
SCAPHOPODA:				
Dentalium cooperi Gabb		×		×
Dentalium stramineum Gabb	×	×	×	×
CEPHALOPODA:				
Aturia mathewsoni Gabb			×	

[16] Species supposed to be characteristic of this horizon.

Locality 57; sandstone, cuts along O. W.-Milwaukee Railway east of Balch, Washington. (H. Hannibal.)

Locality 58; shaly sandstone, bluffs along Olequa Creek at old Ainslee Mill below Winlock, Washington. (H. Hannibal.)

Locality 113; shaly sandstone, bluffs along Cowlitz River below mouth of Drew Creek, 1½ miles east of Olequa, Washington. (H. Hannibal.)

Locality 145; shaly sandstone, water-tunnel on hill east of Chehalis, Washington. (H. Hannibal.)

Partial List of Species in the Olequa Horizon of the Tejon Series (Middle Eocene) at Little Falls, Washington.

	65	66	68	70	73	74	75
PELECYPODA:							
Avicula pellucida Gabb	...	...	×	...	...	...	...
Barbatia morsei Gabb	×	...	×	...	...	×	...
Cardium breweri Gabb	×	×	...	...	×	...	...
Cardium olequænsis Wvr.[17]	...	×	×	×	...	×	...
Crassitellites compacta Gabb	...	...	...	...	...	×	...
Crassitellites grandis Gabb	...	...	...	×	...	...	...
Crassitellites washingtoniana Wvr.[17]	...	...	×	...	×	...	...
Cyrena brevidens White	...	...	×	...	...	...	...
Macrocallista conradiana Gabb	×	...	×	×	...	...	...
Marcia quadrata Gabb	×	...	...	...	...	...	...
Modiolus ornatus Gabb	×	...	...	×	×	...	...
Ostrea idriænsis Gabb	×	×	×	×	...	×	×
Pecten landesi Arn.[17]	...	×	...	×	...	...	...
Septifer dicrotomus Gabb	...	...	...	×	...	...	...
Solen parallelus Gabb	...	×	...	...	×	...	...
Tellina horni Gabb	...	×	...	...	...	...	...
Venericardia horni Gabb[17]	×	×	×	...	×	×	×
GASTEROPODA:							
Amauropsis alveata Conr.	×	×	...	...	×	...	...
Calyptræa excentrica Gabb	×	...	×	×	×	...	×
Ficopsis horni Gabb	×	×	...	×	×	...	...
Ficus mamillatus Gabb	...	×	...	...	...	...	...
Polinices horni Gabb	...	×	×	×	...	...	...
Polinices secta Gabb	...	×	×	...	×	...	...
Pseudoliva volutæformis Gabb	...	×	...	...	×	...	...
Rimella simplex Gabb	×	×	...	×	...	...	...
Sinum obliquum Gabb	...	×	×	...	...	...	...
Turritella uvasana Conr.	×	...	×	×	×	×	...
SCAPHOPODA:							
Dentalium cooperi Gabb	...	...	×	...	...	...	...
Dentalium stramineum Gabb	×	×	×	...	...	...	...

[17] Species supposed to be characteristic of this horizon.

Locality 65; sandstone, bluffs along Olequa Creek between falls and town, Little Falls, Washington. (H. Hannibal.)

Locality 66; tuffaceous sandstone, bluffs at junction of Olequa and Stillwater Creeks, Little Falls, Washington. (H. Hannibal.)

FIG. A.

FIG. B.

FIG. A. Steeply tilted Arago beds (Tejon series) at Mussel Reef west of Coos Bay, Oregon.

FIG. B. Olequa beds (Tejon series) near old log dam on Stillwater Creek, Little Falls, Washington.

Locality 68; sandstone and tuffaceous marl, bluffs on Stillwater Creek at old logdam and for one fourth of a mile below, Little Falls, Washington. (H. Hannibal.)

Locality 70; tuffaceous sandstone, bluffs along Stillwater Creek three fourths of a mile west of junction with Olequa Creek, Little Falls, Washington. (H. Hannibal.)

Locality 73; basalt tuff, cut on Portland-Tacoma railway two and one half miles south of Little Falls, Washington. (H. Hannibal.)

Locality 74; sandstone, gulch below Backstrom ranch, Brim Creek, Little Falls, Washington. (H. Hannibal.)

Locality 75; lignitic sandstone, bluffs three fourths of a mile above Con Murphy ranch on Stillwater Creek, Little Falls, Washington. (H. Hannibal.)

forms are present in the Swauk formation at Liberty, Washington, it is probable that the two deposits on opposite sides of the Cascade Mountains are approximately contemporaneous.

An excellent plant locality in the Olequa formation occurs on Olequa Creek above Little Falls, another is situated in the hills west of Castle Rock. The plant localities at the Carbonado and Wilkeston coal mines, South Prairie Creek above the Burnett Mine, the Bellingham and Lake Whatcom mines, and near Maple Falls on Mt. Baker may be referable to this horizon.

The following marine fauna was collected on Olequa and Stillwater Creeks near Little Falls.

Arago Formation.

The type section of the Arago formation[18] is taken across the strike of a steeply tilted fault-block which may be estimated to include approximately 10,000 feet of alternating marine and freshwater sediments, partly arkose and partly tuffaceous in character, without the base or top of the formation being exposed. A much larger area in which more than 15,000 feet of sediments are represented extends eastward from Coos Bay to the base of the Cascade Mountains and northward along the west flank of the Cascades and through the heart of the Coast Range, besides underlying and outcropping in the Willamette Valley across which the formation was once continuous. In the northward extension of the Arago in Oregon the sedimentary deposits become more and more replaced

[18] See J. S. Diller, Coos Bay Folio, No. 73, U. S. Geol. Sur., 1901.

by basic volcanic flows and agglomerates, until on the Santiam River east of Albany and the Nehalem River in Clatsop and Columbia Counties only igneous rocks are present, the few fragmentary fossils on which the determination of the age of these lavas is based being obtained from coarse tuffs.

Partial List of Species in the Arago Horizon of the Tejon Series (Middle Eocene) of Southwestern Oregon and the North Coast of Washington.

	32	33	40	99	116	154
PELECYPODA:						
Cardium breweri Gabb	...	...	...	×	×	...
Cardium cooperi Gabb	...	...	...	×	...	...
Corbula horni Gabb	...	...	...	×	×	...
Crassitellites compacta Gabb	...	...	...	×	...	...
Crassitellites uvasana Conr	×	...	...	×	...	...
Cyrena brevidens White	...	×	...	...	...	...
Glycymeris cor Gabb[21]	...	...	...	×	×	...
Macrocallista conradiana Gabb	×	...	...	×	×	...
Marcia quadrata Gabb	...	...	...	...	×	...
Meretrix horni Gabb	...	×	...	...	...	...
Miltha turneri Stanton	...	×	...	...	...	...
Modiolus ornatus Gabb	×	×	...	×	×	...
Ostrea idriaensis Gabb	...	×	...	×	×	×
Septifer dichrotomus Gabb	...	...	...	...	×	...
Solen parallelus Gabb	×	...	...	×	...	...
Tellina horni Gabb	×	...	...	...	...	...
Tellina longa Gabb	...	×	...	...	...	...
Tellina remondi Gabb	×	×	...	...	...	...
Venericardia horni Gabb (var. with obsolete ribs)[19]	×	...	...	×	×	×
GASTEROPODA:						
Amauropsis alveata Conr	...	...	...	×	×	...
Calyptræa excentrica Gabb	...	...	...	×	×	...
Conus sinuatus Gabb	...	...	...	×	...	...
Ficopsis horni Gabb	×	...	...	×	...	...
Loxotrema turrita Gabb	...	...	...	×	...	...
Olivella mathewsoni Gabb	...	...	...	×	...	...
Polinices globosa Gabb[21]	...	...	...	...	×	...
Polinices horni Gabb	×	...	...	...	...	...
Polinices shumardiana Gabb[21]	...	...	...	×	×	...
Potamides carbonicola Cooper[21]	...	...	...	×	...	...
Sinum obliquum Gabb	×	...	...	...	...	...
Strepsidura whitneyi Gabb	×	×	...	...	...	...
Tritonium californicum Gabb	...	...	...	...	×	...
Turris io Gabb	×	...	...	...	...	...
Turritella uvasana Conr	×	...	×	×	×	...
SCAPHOPODA:						
Dentalium stramineum Gabb	×	×	...	...	...	...
BRACHIOPODA:						
Terebratulina tejonensis Stanton	...	...	...	...	...	×

[19] Species supposed to be characteristic of this horizon.

Locality 32; sandstone and shale, seacliffs between mouth of Big Creek and Cape Gregory, Coos Bay, Oregon. (H. Hannibal.)

Locality 33; sandstone and shale, seacliffs at Mussel Reef between Coos Head and Cape Gregory, Coos Bay, Oregon. (H. Hannibal.)

Locality 40; sandstone, one fourth of a mile below top of grade north of Five-mile Creek, Bandon, Oregon. (H. Hannibal.)

Locality 99; tuffaceous sandstone, bluffs along Little River at junction with north fork of Umpqua River, Glide, Oregon. (H. Hannibal.)

Locality 116; basalt tuff, seacliffs between pier and Point Crescent, Port Crescent, Washington. (H. Hannibal.)

Locality 154; basalt tuffs, seacliffs immediately southwest of Tongue Point, Port Crescent, Washington. (H. Hannibal.)

On the north coast of Washington the senior author[20] has termed a series of coarse heavy-bedded basalt tuffs with intercalated flows and a minor element of sandstone the Crescent formation. Collections of fossils from the tuff and sandstone obtained by the junior author in 1912 indicate that this formation is the stratigraphic equivalent of the Arago.

The Benton County hills a mile north of Granger, Oregon, Mary's Peak near Philomath, the Willamette River above Springfield, and the north Santiam River between Lyons and Kingston have yielded excellent plant remains pertaining to this horizon, usually in a white or pink rhyolite tuff intercalated with the basalts. Knowlton[21] has also described plants from a locality in the Arago near Comstock in Douglas County and another on Coal Creek in Lane County. Several near Ashland may represent the same horizon.

The following fauna was obtained from the type section south of Coos Bay and from points on the Umpqua River, Oregon, and the north coast of Washington.

Oligocene Deposits—the Status of the Oligocene of the Pacific Coast.

Until a comparatively few years ago the tertiary of the Pacific Coast was classified on a three-fold basis—Eocene, Miocene and Pliocene, and the term Oligocene was a vague indefinite division

[20] Arnold, R., *Bull. Geol. Soc. Am.*, XVII., 1906, p. 460.

[21] 20th Ann. Rept. U. S. Geol. Sur., Pt. III., 1900, pp. 37–64, Pl. I.–V.; Bull. 204, U. S. Geol. Sur., 1902, p. 111.

recognized by European geologists, but no equivalent strata were known on the Pacific Coast. In 1898 Dall[22] used the term Oligocene for the first time in connection with Pacific Coast stratigraphy to cover the "*Aturia* bed," Astoria shales, and doubtfully (and correctly so since it is not a homogenous formation) the Tunnel Point beds of the Oregon Coast. Following this the senior writer[23] placed the San Lorenzo formation of California in the Oligocene on the basis of its equivalence to strata referred to that period on the north Pacific Coast.

Were the Pacific Coast Tertiary the standard for the world it is obvious that a three-fold division would be recognized. The lowest member would consist of the Martinez and Tejon, equivalent to the present Eocene. The succeeding division would embrace the Sooke, Astoria, Vaqueros, and Monterey and correspond to what has been commonly called Oligocene and Lower Miocene. The third would include the numerous usually local formations of which the Empire is the oldest and the Elk River and Deadman Island or Santa Barbara Pliocene the youngest, in other words the middle and upper Miocene and Pliocene, there being no well-marked hiatus in this part of the world between beds of Miocene and Pliocene age, as these divisions are currently recognized.

A direct correlation between the Pacific Coast marine Tertiary and the deposits of Europe and bordering the Gulf of Mexico is impossible owing to the almost total absence of identical species except in the Eocene. The nummulites and corals which have been depended upon to establish the contemporaneity of the Oligocene of Europe and the Antilles are not known on the Pacific Coast, and there do not appear to be any other forms that will serve the purpose. However an assumption that approximately the same time interval is represented by the Pacific Coast deposits may be based on certain broad resemblances.

In the closely allied succession of strata commencing with the Sooke and terminating with the Monterey, the oldest beds lack so

[22] "A Table of North American Tertiary Horizons Correlated with One Another and Those of Western Europe with Annotations," 18th Ann. Rept. U. S. Geol. Sur. (II.), 1898, p. 323–348.

[23] Prof. Pap. 47, U. S. Geol. Sur., 1906, p. 15 ff.

far as known any recent species of mollusca while the number gradually increases to about 6 per cent. of the fauna in the Monterey. The proportion of species extending from the Monterey into the Middle Miocene is somewhat greater—perhaps 25 per cent. Two or three long-lived species known in the Eocene range through the entire Sooke-Monterey succession. With two notable exceptions, the Sooke and Twin River formations, this entire succession is decidedly subtropical in facies. There is a conspicuous element of distinctly Eocene-Oligocene genera throughout, such as *Crassitellites, Aturia, Molopophorus, Exilia, Perissolax, Priscofusus, Strepsidura,* and giant Turritellas, associated with an exceptionally large number of species of *Turris, Patella, Barbatia, Macrocallista, Eudolium,* giant Limas, and other usually tropical genera unknown or of exceptional occurrence in the later deposits of the district.

This Oligocene facies of the fauna is very obvious in the Sooke and Astoria, but less marked in the Vaqueros owing to the additional presence of *Lyropecten* and giant Ostreas, typical Miocene types which, however, must have had their beginning in earlier strata to have become so widespread and important an element of the Miocene fauna. The Monterey is faunally closely allied to these other beds by numerous identical species, but as far as our present knowledge goes, might be placed equally well in the latest Oligocene or the earliest Miocene on the basis of the general faunal facies.

The Sooke Formation.

Occupying several disconnected areas along the south coast of Vancouver Island from Becher Bay westward to Sombrio River near Port San Juan and perhaps farther, is a formation originally described as probably upper Miocene owing to the boreal type of fauna. This Merriam[24] has termed the Sooke beds. With the exception of the type area between Muir and Coal Creeks several miles west of Sooke where drillings have shown the sediments to be more than 1,500 feet thick, the beds comprise only a few feet of basal conglomerate usually less than the height of the sea cliffs in thickness. These lie directly on the bedrock complex, the Van-

[24] Bull. Dept. Geol. Univ. Cal., II., 1896, p. 101–8.

couver greenstone-diorites, and on Muir Creek a mile or two back from the coast the greenstone is exposed beneath the Sooke in the bed of the Cañon so that the development of the sedimentaries on the coast is evidently only local.

The following fauna was obtained from this formation.

Partial List of Species in the Sooke Formation (Middle Oligocene) of the Southern Coast of Vancouver Island.

	129	130	131
Pelecypoda:			
Macrocallista mathewsoni Gabb.	×		×
Macrocallista newcombei Mrm.[24a]	×		
Mytilus sammamishensis Wvr.	×	×	×
Ostrea idriœnsis Gabb.	×	×	×
Pecten branneri Arn.[24a]	×	×	×
Phacoides acutilineatus Conr.			×
Solen curtus Conr.	×		
Spisula albaria Conr.	×		
Tellina oregonensis Conr.	×	×	×
Yoldia oregona Shum.	×		
Gasteropoda:			
Alectryon newcombei Mrm.[24a]	×	×	×
Bullia buccinoides Mrm.	×	×	
Crepidula prærupta Conr.	×		
Eudolium petrosum Conr.	×		
Natica oregonensis Conr.	×	×	
Patella geometrica Mrm.[24a]	×	×	
Polinices callosa Gabb.	×		
Polinices galianoi Dall.	×	×	
Scaphopoda:			
Dentalium conradi Dall.			×

[24a] Species characteristic of this horizon.

Locality 129; sandstone and conglomerate, seacliffs between Muir and Coal Creeks west of Otter Point, Sooke, Vancouver Island. (C. F. Newcombe and H. Hannibal.)

Locality 130; basal sandstone, seacliffs at Fossil Creek, two miles west of Sherringham Point, Jordan River, Vancouver Island. (H. Hannibal.)

Locality 131; basal sandstone, seacliffs one half of a mile east of Slide Hill telegraph station, Jordan River, Vancouver Island. (H. Hannibal.)

The Astoria Series.

The name Astoria formation as applied to a stratigraphic division of the Oregon Tertiary was first used in print by Cope[25] who

[25] *Am. Nat.*, XIV., 1880, p. 457.

says "the unpublished notes of Prof. Condon, formerly State Geologist, state that the backbone of the Coast Range consists of argillaceous shales, which contain invertebrate and vertebrate fossils, frequently in concretions. Some of the latter are Physoclostous fishes with strongly ctenoid scales. To this formation, Dr. Condon gives the name of *Astoria Shales*. Above this is an extensive Tertiary deposit rich in Mollusca, which is usually interrupted by the central elevations of the mountain axis. Prof. Condon refers this to an Upper Miocene age under the name of the *Solen* beds."

As in the instance of other Tertiary formations named before the modern exact method of describing a type section or area and basing a formation on it came into use, the definition of the Astoria Shales is vague, and has led to the inclusion under that name of nearly all the Lower Miocene-Oligocene of northwestern Oregon in spite of unconfirmed suspicions on the part of several California geologists that more than one horizon was represented there. Under the circumstances it is desirable to go back and see what Condon intended the name to cover.

At the time of Hannibal's visit in 1911 the sequence of faunas and range of species in the North Pacific Coast Oligocene and Lower Miocene were not understood, and except for keeping the material from the several localities at Astoria separate no attempt was made to work out the stratigraphy and it was not until the excellent sections exposed along both coasts of the Straits of Fuca were carefully collected in during the spring and summer of 1912 that a definite clue to the presence of two formations at Astoria was obtained. A second visit was paid to the section there during that summer, and later, through the courtesy of Prof. Collier, Condon's collection at the University of Oregon was briefly examined with the idea of deciding what Condon intended the "Astoria Shales" and "*Solen* beds" to include.

From the Astoria Shales there is in the Condon collection a quantity of invertebrate material and fish remains[26] largely incased in gray limestone concretions, and derived without doubt from the

[26] See the forms figured in the Atlas Geol. Wilke's Expl. Exp., 1849, Pl. XVI.–XVII.

low westward dipping monocline of ashy shales which extends from above Tongue Point, several miles up the Columbia River, to Smith Point below the city, forming an unbroken bluff back of the town beneath the scattered areas of Pliocene basalt. Most of the distance these shales reach down to the water's edge and quantities of round or kidney shaped gray limestone concretions are washed out of them by the combined action of the tide and river currents. Practically the entire succession of beds in this monocline represent the Seattle horizon and it is probable that this is what Condon intended to be his type section if he had any specific section in mind. However, the collections and description indicate that he also intended to include in the Astoria the San Lorenzo Shales of Clatsop and Columbia counties which conformably underlie the Seattle beds, and make up to a much greater degree the sedimentary portion of the backbone of the Oregon Coast Range.

The "*Solen* beds" evidently comprised three things, the Empire sandstone of the Coos Bay district with *Solen sicarius* Gld., the sandstones with *Solen curtus* Conr. at the foot of 19th Street at Astoria, unconformable on the Astoria Series and from the accompanying fauna evidently Monterey,[27] and the basal San Lorenzo tuffs at Smith's quarry near Eugene with *Solen curtus* Conr. As this last locality is isolated from the main Astoria area and the fauna is quite distinct from that in any of the shales of the Astoria, though the difference is entirely the result of the character of the bottom at the time the beds were laid down, it is not surprising that Condon should have supposed it to represent a horizon nearer to the Monerey locality at Astoria which contains one or two common species.

The writers propose therefore to use the name Astoria Series, not in a loose sense for all the Oligocene-Lower Miocene of western Oregon but as a general name for the conformable sequence of beds here divided on palaeontological evidence into two horizons, the San Lorenzo and Seattle formations. To these are added on the north coast of Washington a third division, soft semicoherent beds everywhere else removed by erosion before the deposition of the Monterey, the Twin River formation.

[27] See list from here in connection with the description of the Monterey formation.

FIG. A.

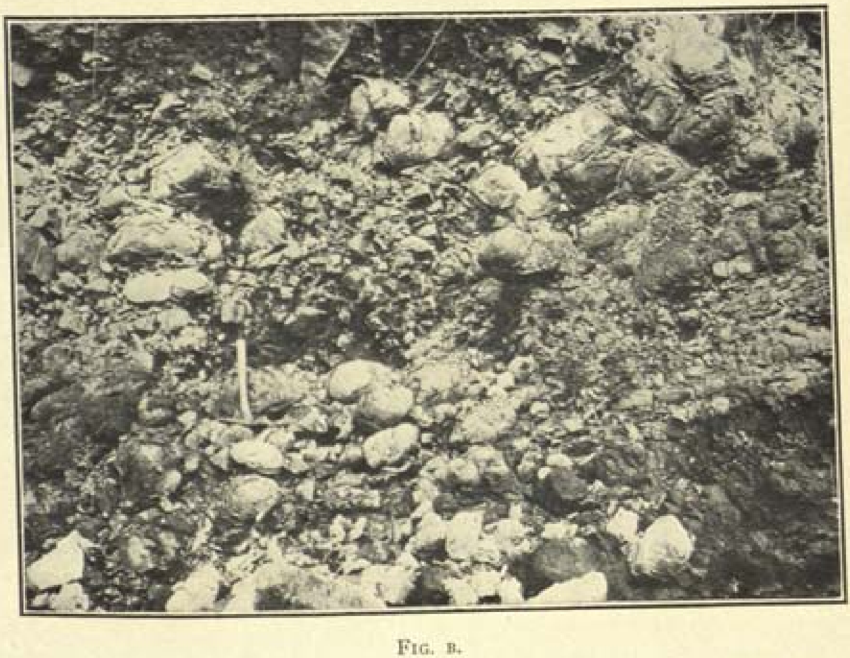


FIG. B.

FIG. A. Tuffaceous San Lorenzo sandstone (Astoria series) at old Smith Quarry, Eugene, Oregon.

FIG. B. Weathered basic tuffs interbedded in San Lorenzo formation (Astoria series) on Vance Creek southwest of Union City, Washington.

Astoria Series

- Twin River formation (zone of *Acila gettysburgensis* Rgn., *Turritella oregonensis* Conr., and *Polinices olympidii* Rgn.).
- Seattle formation (zone of *Acila gettysburgensis* Rgn., *Turcicula washingtoniana* Dall, *Turritella newcombei* Mrm., and *Macrocallista vespertina* Conr.).
- San Lorenzo formation (zone of *Acila shumardi* Dall and *dalli* Arn., *Turritella newcombei* Mrm., *Turcicula columbiana* Dall, and *Macrocallista pittsburgensis* Dall).

The average thickness of the Astoria Series is not less than 12,000 feet, but at some points it attains a much greater development. In the Cape Flattery section about 17,000 feet of apparently conformable coarse sandstones and conglomerates, derived largely from the bedrock series of Vancouver Island, from their fossil contents appear to belong exclusively to the San Lorenzo horizon. The base of the section is cut off by faulting at the mouth of the Soo-es River while the uppermost beds pitch beneath the waters of the Straits of Fuca. Between Winlock and Shoalwater Bay, also in Washington, is a monotonous westward dipping succession of the Astoria Series which if aggregated would total more than 50,000 feet of beds. The paucity of outcrops and the recurrence of certain igneous flows and tuffs associated with the same basal San Lorenzo fauna suggests the presence of a repetition by step faulting which, with the limited time spent in this district of heavy forests, it was impractical to trace out.

The San Lorenzo Formation.

The name San Lorenzo formation has been used by the senior writer[28] for a series of sandstones and diatomaceous shales in the Santa Cruz Mountains, California. Nearly the entire San Lorenzo fauna reappears at a definite horizon in the Tertiary of the North Pacific Coast, *i. e.*, the lowest faunal division of the Astoria Series.

[28] Prof. Pap. 47, U. S. Geol. Sur., 1906, p. 16; Santa Cruz Folio No. 163, U. S. Geol. Sur., 1909; *Proc. U. S. Nat. Mus.*, XXXIV., No. 1617, 1908, p. 348.

It is therefore convenient to use the name San Lorenzo here as well as in California.

On the North Pacific Coast the San Lorenzo ordinarily consists of two members; a basal sandstone and conglomerate varying from 10 to 500 feet or more in thickness and composed largely of worked over volcanic ejectmenta, lying on the basalt or andesite flow which at many points marked the opening of the Astoria epoch, or directly on older rocks; and a shale member several thousand feet thick ordinarily arenaceous, gray and massive, less frequently ashy and dark colored, or calcareous and bluish. Seen under the microscope this shale is composed largely of fine volcanic detritus and has little of the organic character of the San Lorenzo shale of California.

The principal areas of the San Lorenzo formation on Vancouver Island form the narrow intermittent strip of Oligocene sandstones and shales bordering the southwest coast from Sombrio River west to Barkley Sound. In Washington the conglomerates of the Cape Flattery section and eastward to Shroud Head; the sandstones and shales overlying the Oligocene basalts and andesites south and west of Port Townsend; the sandstones overlying the lower Astoria basalts west of Port Orchard Sound and forming the lower half of the Bainbridge Island section of the Seattle Monocline; the shales overlying the basal Astoria basalts north and east of Oakville, Porter, and Elma; the lowest Oligocene exposed in the Lincoln Creek section; and a large part of the monocline previously mentioned as occurring west of Winlock including the Winlock, Pe Ell, Holcomb, Skamokawa and Upper Nasel River exposures are noteworthy. In Oregon the Astoria shales south of the Columbia River at Clatskanie, Scapoose, the upper Nehalem Valley, and West Dairy Creek, isolated exposures about the borders of the Willamette Valley at Silverton, McCoy, and overlying the Eocene basalts at Eugene and Springfield, the lowest beds of the westward dipping monocline between Blodgett and Newport, and the steeply dipping section exposed in the seacliffs south of the entrance to Coos Bay between Basendorfs (Miner's Flat) and Tunnel Point should be regarded as contemporaneous. The so-called Pliocene of the Yahates River belongs also to this horizon.

A typical San Lorenzo fauna has been collected from the area north and east of Porter, Washington.

Partial List of Species in the San Lorenzo Horizon of the Astoria Series (Middle Oligocene) of the Porter-Oakville District, Washington.

	50	51	52	53	54	55	56	109	207
PELECYPODA:									
Cardium lorenzoanum Arn.	×	×	×	×	×	...	×	...	...
Crenella porterensis Wvr.	×	...	×	×	×	...	...	...	...
Ervilia oregonensis Dall[29]	...	×	...	...	...	...	...	...	...
Macrocallista mathewsoni Gabb	...	...	...	...	...	...	...	×	...
Macrocallista pittsburgensis Dall[29]	...	...	...	×	...	...	...	...	...
Malletia chehalisensis Arn.[29]	×	...	...	×	...	...	...	...	...
Marcia oregonensis Conr.[30]	×	...	...	...	...	...	...	...	...
Ostrea idriænsis Gabb	...	×	...	...	...	...	...	...	...
Pecten branneri Arn.[29] (*P. proavus* Arn., *P. washburnei* Arn.)	...	×	...	...	...	...	...	×	...
Pecten peckhami Gabb	...	...	×	...	×	×	...	...	×
Semele gayi Arn.[29]	...	×	...	...	...	...	...	...	...
Thracia trapezoidea Conr	...	...	...	×	...	...	...	...	...
Thyasira bisecta Conr.[30]	...	...	...	×	...	...	...	...	...
Yoldia impressa Conr	×	×	...	×	...	...	...	...	×
GASTEROPODA:									
Epitonium rugiferum Dall[29]	...	×	...	...	...	...	...	...	...
Hipponyx carpenteri Arn.[29]	...	×	...	...	...	...	...	...	...
Molopophorus gabbi Dall[29]	...	...	...	...	...	...	...	×	...
Patella mateoensis Arn.[29]	...	×	...	...	...	...	...	...	...
Turcicula columbiana Dall[29]	...	...	...	...	×	...	...	×	...
Priscofusus hecoxi Arn.[29]	×	...	...	×	×	...	×	×	...
Priscofusus sanctæcrucis Arn.[29]	...	×	...	...	...	...	...	...	...
Turritella newcombei Mrm.[29]	×	×	×	×	×	×	×	...	...
SCAPHOPODA:									
Dentalium conradi Dall	×	×	×	×	×	×	×	...	×
CEPHALOPODA:									
Aturia angustata Conr	...	...	...	...	...	...	...	...	×
BRACHIOPODA:									
Terebratalia occidentalis Dall[30]	...	×	...	...	...	...	...	×	...
Terebratulina caputserpentis L.[30]	...	×	...	...	...	...	...	×	...
ECHINODERMATA:									
Cidaris merriami Arn.[29]	...	...	...	...	...	...	...	...	×

NOTE.—*Thracia condoni* Dall, *Acila cordata* Dall, *dalli* Arn. and *shumardi* Dall, *Strepsidura californica* Arn. (*S. oregonensis* Dall), *Epitonium condoni* Dall and *rugiferum* Dall, and *Miopleionia indurata* Conr. are also characteristic species of this horizon.

Locality 50; massive shaly sandstone, road cuts one fourth of a mile southeast of Porter along Chehalis River, Washington. (H. Hannibal.)

[29] Species characteristic of this horizon.

[30] Species still living.

Locality 51; basal marly tuffs, bluffs at old logdam on Porter Creek one and one half miles above Porter, Washington. (H. Hannibal.)

Locality 52; massive shaly sandstone, bluffs one fourth of a mile below logdam on Porter Creek, Porter, Washington. (H. Hannibal.)

Locality 53; massive shaly sandstone, bluff on Chehalis River below Porter, Washington. (H. Hannibal.)

Locality 54; massive shaly sandstone, bluffs along Porter Creek three fourths of a mile above Porter, Washington. (H. Hannibal.)

Locality 55; massive shaly sandstone, cut on Lytle logging R. R. near top of ridge one mile above switch, Porter, Washington. (H. Hannibal.)

Locality 56; massive shaly sandstone, bluffs along Porter Creek one mile above old logdam, Porter, Washington. (H. Hannibal.)

Locality 109; basal tuffaceous conglomerate, beds immediately overlying basalt at quarry on N. P. R. R., one mile west of Oakville, Washington. (H. Hannibal.)

Locality 207; tuffaceous shale, bluffs along Vances Creek two and one half miles above junction with Skokomish River and thirteen miles above Union City, Washington. (Thos. Purdy, Ed. McCreavy, and H. Hannibal.)

The Seattle Formation.

In the sections at Gettysburg, Bainbridge Island, Lincoln Creek, Nasel River, Nehalem River, Yaquina River, and several other points the San Lorenzo formation is overlain conformably by a succession of beds usually finer grained, thinner bedded, and more calcareous, though the exceptions are too numerous to mention, containing a rather different fauna of less distinctly tropical type and a forerunner of the boreal Twin River fauna which succeeded it. The most fossiliferous exposures of this formation are in the upper beds of the northward dipping Seattle monocline extending from Restoration Point on Bainbridge Island across Admiralty inlet to Alki Point, Georgetown, and Columbia City in Seattle and reappearing east of Lake Washington near the mouth of Coal Creek below Newcastle. The maximum thickness is exposed on Bainbridge Island and aggregates perhaps 3,000 or 4,000 feet of beds.

Other exposures are to be found in Washington on the north coast east of Gettysburg and at the mouth of the Sekiu River, in the uppermost Oligocene beds of the Lincoln Creek section, the beds unconformable beneath the Monterey sandstone south of Elma on Delazine Creek, the lower Nasel River and Ilwaco Sections, and the bluffs at Grays River. In Oregon the Astoria Section, the beds at Nehalem Harbor, and those about the head of Yaquina Bay are contemporaneous.

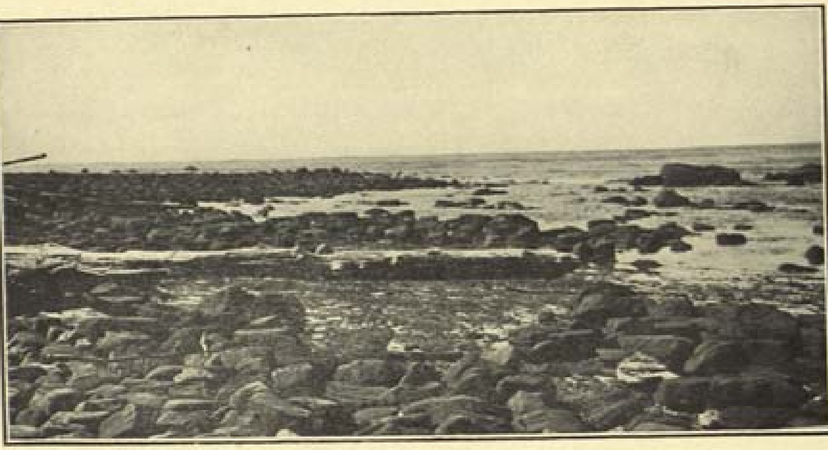


FIG. A.

FIG. B.

FIG. A. Riprap beach formed from thin sandstone beds intercalated with Seattle shales at mouth of Sekiu River, north coast of Washington.

FIG. B. Massive tuffaceous San Lorenzo shales (Astoria series) on Chehalis River at Lincoln Creek, Washington.

The following fauna was obtained from the Seattle Monocline and at Astoria.

Partial List of Species in the Seattle Horizon of the Astoria Series (Middle Oligocene) of Seattle District, Washington and at Astoria, Oregon.

	Oregon			Washington				
	46	47	273	48	49	103	206	261
PELECYPODA:								
Acila gettysburgensis Rgn.[21]	...	...	×	×	×	×	...	×
Cardium lorenzoanum Arn.	...	...	...	×	...	×	...	...
Crenella porterensis Wvr.[21]	...	...	...	×	...	×	×	...
Limopsis nitens Conr.[21]	×	...	...	...	...	...	...	...
Macrocallista vespertina Conr.[21]	...	...	...	...	...	×	×	×
Marcia oregonensis Conr.[22]	...	...	...	×	×	×	...	×
Modiolus ynezianus Arn.	...	...	...	×	...	×	...	...
Mytilus sammamishensis Wvr	...	...	...	...	...	...	×	...
Nucula townsendi Dall	...	...	...	...	...	×	...	...
Panope generosa Gld.[22]	...	...	...	...	...	...	×	×
Pecten peckhami Gabb	...	×	×	...	×	...	...	...
Pecten waylandi Arn.[21]	×	×	×	...	...	...	...	...
Phacoides acutilineatus Conr	...	...	...	×	×	×	×	...
Solemya ventricosa Conr.[21]	...	...	...	...	...	×	...	...
Solen curtus Conr	...	...	×	...	...	×	×	×
Spisula albaria Conr	...	...	...	...	...	...	×	...
Tellina lorenzoensis Arn. (*Macoma moliniana* Dall)[21]	...	...	...	×	×	×	×	...
Tellina obruta Conr	...	...	...	×	...	×	...	...
Tellina oregonensis Conr	...	...	...	×	...	...	×	×
Thracia trapezoidea Conr	...	...	...	...	...	×	...	...
Thyasira bisecta Conr.[22]	...	...	...	×	...	×	...	...
Venericardia castor Dall[21]	...	...	...	...	...	×	×	×
Yoldia impressa Conr	...	...	...	×	...	×	×	×
Yoldia oregona Shum	...	...	...	...	...	...	×	...
GASTEROPODA:								
Crepidula prærupta Conr	...	...	...	...	...	×	×	×
Eudolium petrosum Conr	...	...	...	×	×	×	...	...
Miopleionia indurata Conr.[21]	×	...	...	...	...	×	...	...
Natica oregonensis Conr	...	...	...	×	×	×	...	...
Turcicula washingtoniana Dall[21]	...	...	×	×	×	×	...	...
Turritella newcombei Mrm.[21]	...	...	...	...	...	×	×	...
SCAPHOPODA:								
Dentalium conradi Dall	...	...	...	×	...	×	×	×
CEPHALOPODA:								
Aturia angustata Conr	...	...	×	×	...	×	...	...
BRACHIOPODA:								
Hemithyris astoriana Dall[21]	×	...	...	...	...	...	...	...

Locality 46; ashy shales with limestone nodules, beach at foot of 46th Street, Astoria, Oregon. (H. Hannibal.)

[21] Species characteristic of this horizon.

[22] Species still living.

Locality 47; ashy shales with limestone nodules, beach between foot of Hull Street and Smith Point, Astoria, Oregon. (H. Hannibal.)

Locality 273; ashy shale, bluff back of town between 1st and 13th Streets, Astoria, Oregon. (H. Hannibal.)

Locality 48; sandy shale, beach from Alki Point south one fourth of a mile along shore of Puget Sound, Seattle, Washington. (H. Hannibal.)

Locality 49; massive shale, railroad cuts between Argo and Georgetown Stations, Seattle, Washington. (H. Hannibal.)

Locality 103; shaly sandstone, beach between south side of entrance to Blakely Harbor and Restoration Point, Bainbridge Island, Washington. (H. Hannibal.)

Locality 206; sandstone, bluffs overlooking Andrews Bay, Lake Washington, three fourths of a mile east of Columbia City Station, Seattle, Washington. (H. Hannibal.)

Locality 261; sandstone, bluffs along Coal Creek three fourths of a mile above Lake Washington, Newcastle, Washington. (H. Hannibal.)

Twin River Formation.

Conformable above the Seattle beds in the section of the Astoria series between Port Crescent and Pysht River on the north coast

Partial List of Species in the Twin River Horizon of the Astoria Series (Middle Oligocene) of the North Coast of Washington.

	120	121	122	158	159
PELECYPODA:					
Acila gettysburgensis Rgn.[33]	×	×	×		×
Cardium lorenzoanum Arn.	×		×		
Marcia oregonensis Conr. (*M. subdiaphana* Cpr.)[34]	×				
Modiolus ynezianus Arn.			×		
Mytilus sammamishensis Wvr.	×				
Pecten peckhami Gabb.					×
Phacoides acutilineatus Conr.	×		×		
Solen curtus Conr.	×				
Tellina obruta Conr.	×	×	×		×
Thracia trapezoidea Conr.	×				
Thyasira bisecta Conr.[34]	×	×	×		
GASTEROPODA:					
Eudolium petrosum Conr.	×		×		×
Natica oregonensis Conr.	×		×		×
Polinices galianoi Dall.				×	
Polinices olympidii Rgn.[33]	×		×		
Sinum scopulosum Conr.	×				
Turritella oregonensis Conr.[33]	×		×		
SCAPHOPODA:					
Dentalium conradi Dall.	×		×		×
CEPHALOPODA:					
Aturia angustata Conr.	×				×

[33] Species characteristic of this horizon.

[34] Species still living.

Locality 120; clay shales, seacliffs west of Twin for a distance of three fourths of a mile along shore, Olympic Peninsula, Washington. (A. B. Reagan, H. Hannibal.)

Locality 121; clay shales and sandstone, seacliffs at Arc Reef Point two and one half miles west of Twin, Washington. (H. Hannibal.)

Locality 122; shaly sandstone, seacliffs one half to three miles east of Twin, Washington. (A. B. Reagan, H. Hannibal.)

Locality 158; sandstone and shale, seacliffs at small point west one mile from Deep Creek, Twin, Washington. (H. Hannibal.)

Locality 159; shale and sandstone, seacliffs one and one half miles east of Pillar Point, Twin, Washington. (H. Hannibal.)

of Washington and extending from about three miles east of Twin River west nearly to Pysht Bay where it is faulted against the Monterey, is a stretch of soft clay-shales perhaps 2,000 feet thick intercalated with occasional thin beds of sandstone that wash out on the beach as flags. These beds, both shales and sandstone, contain a fauna of a marked boreal type. Most of the species are undescribed, but the few already known indicate that it is quite as closely allied to the Vaqueros and Monterey as to the San Lorenzo and Seattle faunas, yet sufficiently distinct from all of these.

The horizon is named from the locality where the best fossil collecting was obtained.

The Monterey Formation (Oligocene-Miocene).

The term "Monterey Shales" has long been current in the geological literature of California for the great series of diatomaceous shales first described by Blake[35] and Lawson[36] from Monterey in that state. While these deposits are particularly interesting to the oil geologist on account of their petroliferous character, their affinities have long been uncertain owing to the impoverished molluscan fauna. Dr. J. P. Smith[37] was probably the first writer to correctly interpret their relations, considering them as simply an off-shore facies of the beds variously called the Upper Vaqueros, Temblor, *Agasoma* zone, and *Turritella ocoyana* beds. Recently the junior writer visited the type section and had no difficulty in securing a

[35] Blake, W. P., *Proc. Phila. Acad. Nat. Sci.*, VII., 1855, p. 328–331.

[36] Lawson, A. C., *Bull. Geol. Univ. Cal.*, I., 1893, p. 22.

[37] *Proc. Cal. Acad. Sci.* (4th Ser.), III., 1912, p. 161–182.

small but characteristic fauna from limestone lenses intercalated in the diatomaceous shales.

Partial List of Species in the Monterey Formation (Oligocene-Miocene) Between Monterey and Carmel, California.

PELECYPODA:

Arca devincta Conr. (*A. montereyana* Osmont).[38]
Leda taphria Dall.[39]
Leda penita Conr.[38]
Marcia congesta Conr. (*Tellina congesta* Conr.).[38]
Nucula townsendi Dall (ranges into Astoria).
Pecten peckhami Gabb (ranges into Tejon).
Venericardia montereyana Arn.[38]

GASTEROPODA:

Caesia arnoldi F. M. And. (ranges into Empire).
Ficus kernianus Cooper.[38]
Polinices saxea Conr.[38]
Turritella cf. variata Conr.[38]

This unmistakably fixes the identity of the *Agasoma* zone of California and what the senior writer[40] has described from the north coast of Washington as the Clallam formation with the Monterey shale, and it is proposed to unite all these under this prior name. It should be specifically understood however that another formation in California, the Lower Vaqueros, *i. e.*, the zone of the beds in the Las Vaqueros Valley, to which the name Vaqueros was applied by Hamlin[41] and from which were obtained such species as *Mytilus expansus* Arn., *Ostrea* cf. *Tayloriana* Gabb, *Ostrea* cf. *Titan* Conr., *Pecten magnolia* Conr., and *Turritella inezana* Conr., are not included in the Monterey. This formation lies unconformably below the Monterey in the Santa Monica Mountains, in the Santa Clara River Valley (where it is more particularly characterized by *Scutella fairbanksi* Arn.), and in the Santa Cruz Mountains. For it the name Vaqueros is retained.

Perhaps the only objection to the use of the term "Monterey Formation," and certainly not an important one from a palæonto-

[38] Species characteristic of this horizon.
[39] Species still living.
[40] *Bull. Geol. Soc. Am.*, XVIII., 1906, p. 461.
[41] Water Supply Paper 89, U. S. Geol. Sur., 1904, p. 14.

FIG. A.

FIG. B.

FIG. A. Landsliding in soft clayshales of Monterey formation on O. W. Milwaukee Railway between Cosmopolis and North River, Washington.

FIG. B. Jump-off-Joe rock and Cape Foulweather light-house, Newport, Oregon. The rocks in the foreground are Monterey sandstones and shales, in the distance basalts intruded in the Monterey.

logical standpoint, is total absence on the North Pacific Coast of any beds in this formation, or in any other formation for that matter, lithologically similar to the diatomaceous shales so prevalent in Monterey of California. This became vital, however, from the point of view of the economic geologist since upon the presence of such shales or similar organic deposits equally lacking here, depends the possibilities of the discovery of petroleum in commercial quantities. Except for coal near Clallam Bay, Washington,[42] and on the North Nehalem River in Oregon[43] no organic products of economic value are known in this formation.

The Monterey formation of this region ordinarily consists of two members; the lower a massive buff sandstone often containing thin lignite seams and attaining south of the Chehalis River a thickness of perhaps 1,500 feet; the upper fine soft clay shales perhaps 2,500 feet thick in the same section which is one of the most complete.

To this formation are referred the conglomerates overlying the San Lorenzo shales at Carmanah Point on Vancouver Island; and in Washington: the Clallam section and the conglomerates unconformable on the Seattle beds between West Clallam and the Hoko River; a small area of Tertiary sandstone faulted into the so-called Cretaceous north of the Hoh River; an area of shales faulted against the Empire formation on the upper Wishkah River; the westward dipping monoclinal section from a few miles west of Elma to North River Junction on the south side of the Chehalis River and equivalent strata south to the Willipa River; and an isolated area beneath the Pliocene basalt on Elocheman River about twelve miles above the Columbia. In Oregon isolated areas lying on the Astoria series or exposed beneath the Pliocene basalt at Mountain Dale, Westport, the foot of 19th Street at Astoria, and the south shore of Tillamook Harbor are of this age as well as a narrow belt of rocks faulted against the Astoria series and extending for several miles up and down the coast west of Newport.

The following species were obtained in the Clallam section and at Astoria.

[42] R. Arnold, Bull. 260, U. S. Geol. Sur., 1905, p. 413–427.
[43] J. S. Diller, 17th Ann. Rept. U. S. Geol. Sur., Pt. I., 1896, p. 494.

Partial List of Species in the Monterey Formation (Oligocene-Miocene) of the Clallam Bay District, Washington, and at Astoria, Oregon.

	45	89	160	161	162	163
PELECYPODA:						
Acila conradi Meek	×	×	...	...	...	×
Arca devincta Conr. (*A. montereyana* Osmont)[44]	×	×	×	×	×	×
Arca trilineata Conr	...	×	...	...	...	...
Diplodonta parilis Conr	×	...	...	...	...	...
Dosinia whitneyi Gabb[44]	...	...	×	×	...	...
Leda penita Conr.[44]	×	×	...	...	...	...
Macoma piercei Arn.[44]	...	...	...	×	...	...
Marcia oregonensis Conr. (*M. subdiaphana* Cpr.)[45]	×	×	...	×	...	×
Modiolus rectus Conr. (*M. directus* Dall)[45]	×	...	...	×	...	...
Panope generosa Gld.[45]	×	×	...	×	...	×
Pecten fucanus Dall[44]	...	×	...	×	...	×
Pecten propatulus Conr.[44]	×	×	×	...	...	...
Phacoides acutilineatus Conr	×	...	...	×	...	×
Solen curtus Conr	×	×	...	×	...	...
Spisula albaria Conr	×	×	...	×	...	×
Spisula catilliformis Conr.[45]	...	×	...	...	...	...
Tellina arctata Conr.[44]	×	×	...	×	...	×
Tellina nuculana Dall[44]	×	...	...	...	...	...
Tellina obruta Conr. (*T. albaria* Conr.)	×	...	...	×	...	×
Tellina oregonensis Conr	×	×	...	...	...	×
Thracia trapezoidea Conr	×	×	...	×	...	×
Thyasira bisecta Conr.[45]	×	...	...	×	...	...
Venericardia subtenta Conr. (*V. quadrata* Dall)[44]	...	...	...	×	...	×
Venus clallamensis Rgn. (*V. ensifera* Dall)[44]	×	×	...	×	...	...
Venus olympidea Rgn.[44]	...	×	...	...	...	...
Yoldia impressa Conr	×	...	...	...	...	...
Yoldia oregona Shum	×	...	...	...	...	...
GASTEROPODA:						
Ampullina oregonensis Dall	×	...	...	...	...	...
Cæsia arnoldi F. M. And.	×	...	...	×	...	...
Chrysodomus nodiferus Conr. (*Fusus stanfordensis* Arn.)	×	×	...	×	...	...
Crepidula prærupta Conr.	×	×	...	×	...	...
Cylichnella petrosa Conr.[44]	×	...	...	...	...	...
Ficus stanfordensis Arn	...	×	...	...	...	...
Fusinus corpulentus Conr. (*F. medialis* Conr.)[44]	×	...	...	...	...	...
Fusinus devinctus Conr.[44]	×	...	...	...	...	...
Natica oregonensis Conr	×	...	...	×	...	...
Polinices saxea Conr.[44]	...	×	...	×	...	...
Priscofusus geniculus Conr.[44]	×	...	...	×	...	×
Sinum scopulosum Conr	×	×	...	...	...	...
Turris wynoocheensis Wvr.[44]	...	...	...	...	...	×
Turritella oregonensis Conr.[44]	×	...	...	...	...	...
SCAPHOPODA:						
Dentalium conradi Dall (*D. petricola* Dall)	×	×	...	×	...	×
CEPHALOPODA:						
Aturia angustata Conr	...	...	...	...	...	×

Locality 45: basal sandstone, beach at foot of 19th Street, Astoria, Oregon. (H. Hannibal.)

[44] Species characteristic of this horizon.

[45] Species still living.

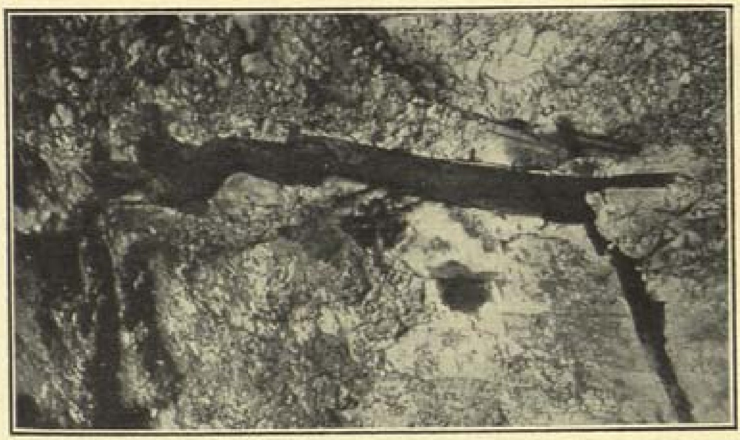


FIG. B.

FIG. A.

FIG. A. Monterey sandstone at Pillar Point near Clallam Bay, Washington.
FIG. B. Sandstone dyke in tuffaceous Empire shales on upper reaches of Wishkah River, Aberdeen, Washington.

Locality 89; basal sandstone and conglomerate, seacliffs eastward from Slip Point for half a mile along shore, Clallam Bay, Washington. (A. B. Reagan, H. Hannibal.)

Locality 160; massive sandstone, seacliffs at Pillar Point near Clallam Bay, Washington. (H. Hannibal.)

Locality 161; shaly sandstone, seacliffs one and one half miles west of Pillar Point near Clallam Bay, Washington. (H. Hannibal.)

Locality 162; carbonaceous sandstone, seacliffs at Clallam coal mine near Clallam Bay, Washington. (H. Hannibal.)

Locality 163; shaly sandstone, seacliffs one and one half miles west of Clallam coal mine near Clallam Bay, Washington. (H. Hannibal.)

The Empire Formation (Miocene).

To beds exposed on the east shore of Coos Bay south of Empire, Oregon, Diller[46] has given the name Empire formation. This horizon the junior writer found in his field work to be widespread in Western Oregon and Washington. In many respects the Empire fauna is peculiar since it evidently represents the oldest distinctly Miocene strata on the Pacific Coast. For, while the fauna is perhaps most closely allied to the *Scutella breweriana-S. gabbi* beds of the San Pablo formation of the San Francisco Bay region in California, the larger proportion of recent species in those deposits and rather marked faunal differences preclude an exact correlation.

In the Empire district about 500 feet of beds, sandstones at the base grading upward into massive shales partially organic in character, but more or less derived from worked over volcanic debris, represent the formation. At Cape Blanco sandstones alternating with compact bedded volcanic ash containing abundant plant remains attain about the same thickness. In the area between Willipa Harbor and Grays Harbor in Washington the base of the formation is represented, being marked by a zone of basalt tuffs and breccias. The most important area, however, lies between the Chehalis Valley and the foot of the Olympic Mountains, where the formation attains a thickness of perhaps 4,000 feet, chiefly sandstones at the base grading upward into massive tuffaceous shales with some intercalated sandstones. Small Empire areas occur on the west coast of the Olympic Peninsula between Cape Grenville and

[46] 17th Ann. Rept. U. S. Geol. Sur., Pt. I., 1896, p. 475.

Partial List of Species in the Empire Formation (Middle Miocene) of the Coos Bay-Cape Blanco District, Southwestern Oregon.

	23	26	31	36	37	39	43	44
PELECYPODA:								
Acila conradi Meek		×			×			
Arca trilineata Conr		×			×			
Cardium coosense Dall[48]				×				
Cardium meekianum Gabb		×		×	×			
Diplodonta parilis Conr		×			×			
Glycymeris grewingki Dall[48] (*G. gabbi* Dall, *G. conradi* Dall)		×			×			×
Macoma astori Dall[48]					×			×
Macoma calcarea Gmel.[49]		×		×			×	
Macoma inquinata Desh.[49]							×	
Marcia oregonensis Conr. (*M. subdiaphana* Cpr.)[49]		×		×			×	×
Modiolus rectus Conr. (*M. directus* Dall)[49]					×			
Mulinia densata Conr. (*M. oregonensis* Dall)					×			
Mya truncata L.[49]				×				
Mytilus middendorffi Grnk. (*M. condoni* Dall)[48]	×	×						
Panomya ampla Dall (*P. chrysis* Dall)[49]							×	
Parapholas californica Conr.[49]							×	
Paphia stayleyi Gabb				×			×	
Pecten coosensis Shum[48]				×		×		
Phacoides acutilineatus Conr					×			
Schizothærus pajaroanus Conr					×			
Siliqua nuttalli Conr. (*S. oregonia* Dall)[49]		×						
Solen sicarius Gld. (*S. conradi* Dall)[49]		×		×	×		×	×
Spisula albaria Conr. (*S. præcursor* Dall)		×		×	×	×	×	×
Tellina aragonia Dall[48]		×			×			
Thracia trapezoidea Conr				×				
Venus securis Shum. (*V. parapodema* Dall)		×			×			
Yoldia impressa Conr				×				
Yoldia oregona Shum					×			
Yoldia strigata Dall				×				
GASTEROPODA:								
Ampullina oregonensis Dall				×				
Argobuccinum cammani Dall[48]				×				×
Argobuccinum coosense Dall[48]							×	
Bathytoma gabbiana Dall[48]				×				
Boreotrophon stuarti Smith[49]				×			×	
Bullia bogachielia Rgn.[48]		×						
Cæsia arnoldi F. M. And.		×			×			
Calliostoma cammani Dall[48]				×				
Calyptræa inornata Gabb				×	×			
Cancellaria oregonensis Dall[48]		×						
Chrysodomus bairdi Dall[48]				×				
Chrysodomus imperialis Dall				×				
Chrysodomus nodiferus Conr. (*Fusus stanfordensis* Arn.)		×						
Crepidula adunca Sby.[49]		×						
Crepidula princeps Conr					×			×
Cymatium pacificum Dall[48]		×		×				
Fusinus coosensis Dall[48]		×		×				×
Miopleionia oregonensis Dall					×			×
Natica clausa B. & S. (*N. consors* Dall)[49]	×	×		×	×		×	×

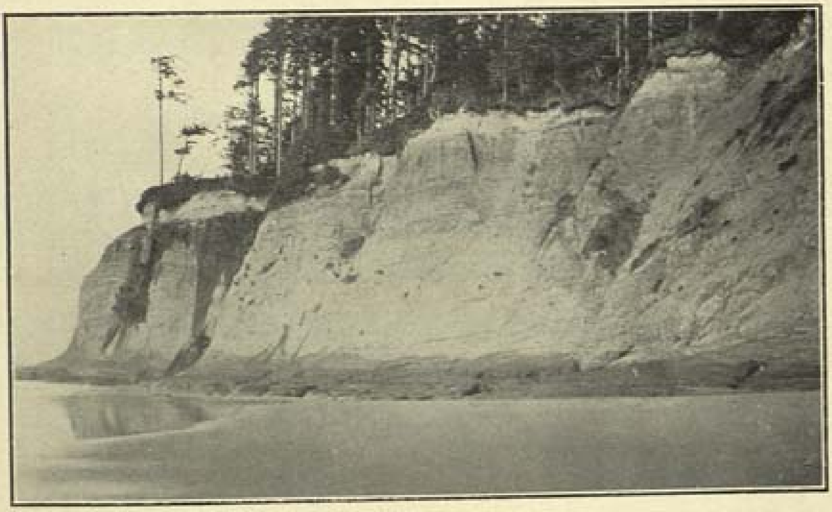


FIG. A.

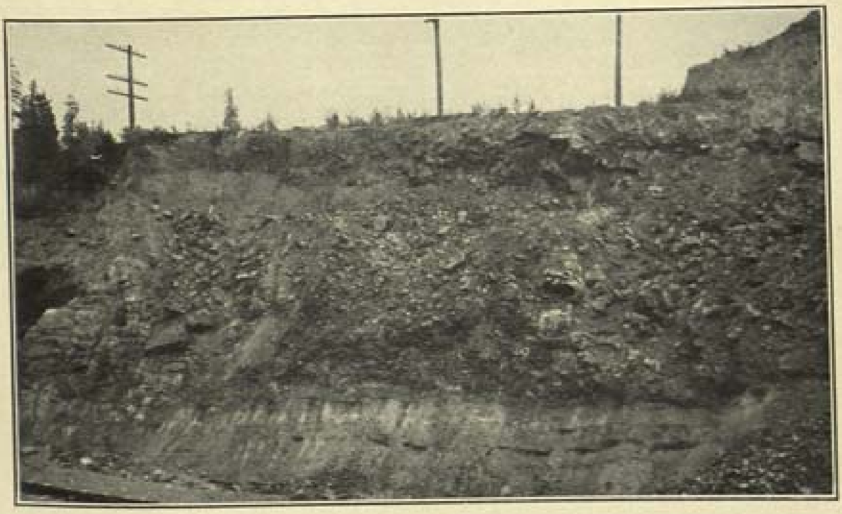


FIG. B.

FIG. A. West face of Coos Head, Coos Bay, Oregon. Empire sandstone overlain by Pleistocene sands.

FIG. B. Pliocene basalts associated with river sands and gravel on Portland-Tacoma Railway below Little Falls, Washington.

	23	26	31	36	37	39	43	44
GASTEROPODA:								
Nucella decemcostata Midd. (*Thais præcursor* Dall)[49]	×	×	...	×	...	...	...	×
Nucella lamellosa Gmel. (*Purpura crispata* Chem.)[49]	...	...	...	...	...	...	...	×
Olivella biplicata Sby.[49]	...	×	...	...	...	...	...	...
Olivella pedroana Conr.[49]	...	...	...	×	...	...	...	...
Phalium æquisulcatum Dall[48]	...	...	...	×	...	...	...	...
Phalium turricula Dall[48]	...	...	...	×	...	...	...	...
Polinices galianoi Dall	...	...	...	×	...	...	...	...
Tegula stantoni Dall[48]	...	...	...	×	...	...	...	...
Turris coli Dall[48]	...	...	...	...	...	...	×	...
Turris impecunia Dall[48]	...	×	...	×	...	...	...	...
Turris perversa Gabb[49]	...	...	...	×	...	...	...	...
Sinum scopulosum Conr	...	...	...	...	...	...	...	×
SCAPHOPODA:								
Dentalium rectius Cpr.[49]	...	...	...	×	...	...	...	...
BRACHIOPODA:								
Discinisca oregonensis Dall	...	...	...	...	...	...	×	...
Terebratalia occidentalis Dall[49]	...	...	...	...	...	...	×	...
ECHINODERMATA:								
Scutella gabbi Rem.[48]	...	×	...	...	×	...	...	...
PISCES:								
Isurus planus Ag	...	...	×	...	...	...	...	...

Locality 23; basal sandstone, seacliffs between Blacklock Point and Floras Lake, Cape Blanco, Oregon. (H. Hannibal.)

Locality 26; basal sandstone, seacliffs southeast of lighthouse for a mile along shore, Cape Blanco, Oregon. (F. F. Wood, H. Hannibal.)

Locality 31; massive shale, beach one fourth of a mile north of South Slough bridge, east shore of Coos Bay, Oregon. (H. Hannibal.)

Locality 36; shaly sandstone, beach between submerged jetty and Fossil Rock, three miles south of Empire, Coos Bay, Oregon. (H. Hannibal.)

Locality 37; basal sandstone, beach for a mile toward Empire from Tarheel Point, Coos Bay, Oregon. (H. Hannibal.)

Locality 39; shaly sandstone, north face of Coos Head, Coos Bay, Oregon. (H. Hannibal.)

Locality 43; basal sandstone, seacliffs between Astoria-Empire unconformity and Goldwashers Gully, coast west of Coos Bay, Oregon. (H. Hannibal.)

Locality 44; basal sandstone, seacliffs between Goldwashers Gully and Coos Head, coast west of Coos Bay, Oregon. (H. Hannibal.)

the mouth of the Quinaielt River, between Cape Elizabeth and Raft River, at the mouth of Raft River, and on the Bogochiel River above

[48] Species characteristic of this horizon.

[49] Species still living.

Mora. The Tertiary rocks of Tchow-un Point,[49a] Queen Charlotte Islands, represent the same horizon.

The following fauna was obtained at Cape Blanco and Coos Bay, Oregon.

The Merced Formation (Miocene-Pliocene).

In terming the latest Miocene or earliest Pliocene deposits of the North Pacific Coast the Merced Formation, the writers recognize the contemporaneity of the Scotia section of Eel River Valley, California, the Coos Conglomerate of Coos Bay, Oregon, and the Miocene-Pliocene portion of the Quinaielt formation near Taholáh, Washington, with the Miocene-Pliocene beds of the Seven-mile section and exposures on Twelve-mile Creek south of San Francisco, California.

As originally constituted by Lawson[50] the Merced formation apparently included two members, the one in question, steeply tilting beds extending in the Seven-mile Beach section from Mussel Rock northward to the highest *Scutella* bed, the other nearly horizontal sands and clays west of Colma containing a small fauna composed entirely of living species. Subsequently Ashley[51] utilized the name Merced for the older portion, pointing out that the upper beds should be considered separately. Recent collections made by the junior writer show conclusively that the upper horizontal beds are Quaternary and, though the contact is obscure, water-worn pebbles containing *Scutella interlinerta* Stimp. present in them indicate an unconformity with the underlying Miocene-Pliocene.

Partial List of Species in the Merced Formation (Miocene-Pliocene) of the San Francisco Peninsula and Eel River Valley, California.

Pelecypoda:

Arca trilineata Conr., *S.*
Cardium meekianum Gabb, *S, E.*
Diplodonta orbella Gld., *S.*[52]
Glycymeris coalingensis Arn., *E.*[53]
Macoma calcarea Gmel., *E.*[52]

[49a] Dawson, G. M., Rept. Geol. Sur. Can., 1788–9 (1880), p. 87*B*, calls this Skonum Point. Dr. C. F. Newcombe informs the writer that Tchow-un is more correct.

[50] Bull. Dept. Geol. Univ. Cal., I., 1894, p. 115–160.

[51] *Jour. Geol.*, III., 1895, p. 441–6.

Macoma nasuta Conr., *S.*[52]
Marcia oregonensis Conr. (*M. subdiaphana* Cpr.), *S, E.*[52]
Mulinia densata Conr., *S, E.*
Panomya ampla Dall (*P. chrysis* Dall), *E.*[52]
Paphia staleyi Gabb, *S, E.*
Paphia tenerrima Conr., *S.*[52]
Pecten caurinus Gld., *S, E.*[52]
Pecten dilleri Dall, *E.*[53]
Pecten healeyi Arn., *S.*[53]
Pecten nutteri Arn., *S.*
Psephidia lordi Baird, *S, E.*[52]
Schizothaerus nuttalli Conr., *S.*[52]
Schizothaerus pajaroanus Conr., *E.*
Siliqua nuttalli Conr., *S, E.*[52]
Solen sicarius Gld., *S.*[52]
Spisula voyi Gabb (*S. alaskana* Dall), *S, E.*[52]
Tellina buttoni Dall, *S.*[52]
Thracia trapezoidea Conr., *E.*
Venus securis Shum., *S.*

GASTEROPODA:

Caesia mendica Gld., *S.*[52]
Chrysodomus stantoni Arn., *S.*[53]
Chrysodomus tabulatus Baird, *S, E.*[52]
Columbella gausapata Gld. (*Astyris richthofeni* Gabb), *S, E.*[53]
Crepidula onyx Sby., *S.*[52]
Crepidula princeps Conr., *S.*
Natica clausa B. & S., *S, E.*[52]
Nucella decemcostata Midd. (*Purpura lima* auct.), *S.*[53]
Nucella lamellosa Gmel., *S, E.*[53]
Nucella saxicola Val., *S.*[52]
Olivella biplicata Sby., *S.*[52]
Polinices galianoi Dall, *S.*
Stylidium eschrichti Midd. (*Bittium filosum* Gld.), *S.*[53]

SCAPHOPODA:

Dentalium rectius Cpr., *E.*[52]

ECHINODERMATA:

Echinarachnius gibbsi Rem., *S.*[53]
Scutella interlineata Stimp., *S.*[53]
Scutella oregonensis Clark, *S, E.*

S—San Francisco Peninsula. *E*—Eel River Valley.

NOTE.—This and succeeding lists from the Merced and Elk River formations should not be used as a basis for determining percentages of species living or extinct. It has not been convenient to identify all the living species in time to include them on the lists, and in addition a number of undescribed extinct forms occur.

[52] Species still living.

[53] Species characteristic of this horizon

The Merced areas on the North Pacific Coast are, without exception, small and isolated. Deposits limited to the basal conglomerates attain in Oregon a thickness of a few feet at two points on the east shore of Coos Bay south of Empire, and again at the point south of Five-mile Creek on the coast near Bandon.

Partial List of Species in the Merced Formation (Miocene-Pliocene) of the Coast of Oregon and Washington.

	Oregon			Washington		
	34	35	98	77	79	80
PELECYPODA:						
Cardium meekianum Gabb	...	...	...	×	...	...
Macoma calcarea Gmel.[54]	...	...	...	×	...	...
Macoma nasuta Conr	×	...	...	...	...	...
Marcia oregonensis Conr. (*M. subdiaphana* Cpr.)[54]	...	...	...	×	...	...
Mulinia densata Conr. (*M. oregonensis* Dall)	×	...	...	...	...	...
Mytilus edulis L.[54]	...	...	...	...	...	×
Ostrea cf. lurida Cpr.[54]	...	...	×	...	...	...
Panope generosa Conr.[54]	...	...	...	...	...	×
Pecten caurinus Gld.[54]	×	...	...	...	...	...
Pecten dilleri Dall[55]	...	...	...	...	×	...
Phacoides annulatus Rve.[54]	...	...	...	×	...	...
Pholadidea penita Conr.[54]	×	...	...	...	...	...
Psephidia lordi Bd.[54]	...	...	×	...	...	...
Solen sicarius Gld.[54]	...	...	...	×	...	...
Spisula albaria Conr	...	...	...	×	...	×
Spisula voyi Gabb (*S. alaskana* Dall)[54]	...	...	×	...	...	...
Thyasira bisecta Conr.[54]	...	...	...	...	×	...
Venus securis Shum	...	...	...	×	...	...
GASTEROPODA:						
Argobuccinum oregonense Redf.[54]	×	...	...	...	...	...
Astræa inequalis Mart.[54]	×	...	...	...	...	...
Cæsia mendica Gld.[54]	...	...	...	×	...	...
Chrysodomus imperialis Dall	×	...	...	×	...	...
Chrysodomus tabulatus Bd.[54]	...	×	...	...	...	...
Gyrineum marshalli Rgn. (*G. mediocre* Dall)	...	...	...	×	...	...
Littorina remondi Gabb (*L. petricola* Dall)	×	×	...	...	...	...
Natica clausa B. & S.[54]	...	...	...	×	×	...
Nucella decemcostata Midd.[54]	...	×	...	×	...	...
Olivella pedroana Conr.[54]	×	×	...	...	...	...
Purpura foliata Mart.[54]	×	...	...	...	...	...
Stylidium eschrichti Midd. (*Bittium filosum* Gld.)[54]	×	...	...	...	...	...
Tritonalia lurida Midd.[54]	...	...	...	×	...	...
Turcica caffea Gabb[54]	...	...	...	×	...	...
Turris perversa Gabb[54]	...	×	...	×	...	...

Locality 34; basal conglomerate and sandstone, Fossil Rock, three and one half miles south of Empire, Coos Bay, Oregon. (H. Hannibal.)

[54] Species still living.

[55] Species characteristic of this horizon.

Locality 35; basal conglomerate, point south of Fossil Rock, four miles south of Empire, Coos Bay, Oregon. (H. Hannibal.)

Locality 98; basal conglomerate, seacliffs at point three fourths of a mile south of Five Mile Creek, Bandon, Oregon. (H. Hannibal.)

Locality 77; sandstone, seacliffs from Cape Grenville northward for a mile to long landslide, Taholah, Washington. (H. Hannibal.)

Locality 79; shaly sandstone, seacliffs north of Quinaielt River bar, Taholah, Washington. (H. Hannibal.)

Locality 80; sandstone, seacliffs from Cape Elizabeth northward for three fourths of a mile to big landslide, Taholah, Washington. (H. Hannibal.)

Two areas of soft semicoherent sandstone faulted into the Older Tertiary and Mesozoic rocks on the coast of the Olympic Peninsula near Taholah, Washington, contain a fauna evidently the same age. The thickness here is perhaps 500 feet.

THE ELK RIVER FORMATION (UPPER PLIOCENE).

Extending from the Goldwashers' cabin one and three fourths miles southeast of Cape Blanco south to Garrison Lagoon near Port Orford, Oregon, is a gently southward dipping cliff, essentially a raised beach composed of sands and littoral gravels, blue and more or less concretionized at the base but rusty and hardly consolidated above, perhaps 250 feet thick near their contact with the Empire sandstone lying to the north but gradually dropping down below sea level to the south. This formation has been named by Diller[56] the Elk River beds from an important stream which cuts through the section. As a matter of fact Diller's name was given only to the upper rusty portion of the section while the blue beds conformable below were included with the Empire (Cape Blaco Beds) a procedure not borne out by the character of the fauna. It might be added that there is a marked discrepancy between the dip and strike of the Empire beds and the overlying blue sands where the two formations meet that was apparently overlooked by Diller.

The fauna of the Elk River beds consists chiefly of recent species but associated with them are others common to the Merced, thus establishing the Pliocene age of the formation. In a general way this fauna suggests the Deadman Island or Santa Barbara Pliocene in the boreal facies of the fauna and the small percentage of extinct

[56] Bull. 196, U. S. Geol. Sur., 1902, p. 31.

forms, though the two formations have only one characteristic species, *Turris smithi* Arn., in common.

Partial List of Species in the Elk River Formation (Upper Pliocene), at the Seacliff North of the Mouth of Elk River, Port Orford, Oregon.

(F. F. Wood, H. Hannibal, collectors.)

PELECYPODA:

Cardium corbis Mart.[57]
Cryptomya oregonensis Dall.
Kennerlia grandis Midd.[57]
Leda acuta Conr.[57]
Macoma inquinata Desh.[57]
Macoma nasuta Conr.[57]
Modiolus modiolus L.[57]
Modiolus rectus Conr.[57]
Mya truncata L.[57]
Mytilus californianus Conr.[57]
Mytilus edulis L.[57]
Paphia staminea Conr.[57]
Pecten caurinus Gld.[57]
Psephidia lordi Baird.[57]
Saxidomus giganteus Desh.[57]
Siliqua nuttalli Conr.[57]
Spisula cf. albaria Conr.
Spisula falcata Gld.[57]
Spisula voyi Gabb (*S. alaskana* Dall).[57]
Thracia trapezoidea Conr.
Venericardia ventricosa Gld.[57]

GASTEROPODA:

Amphissa corrugata Rve. and var. *versicolor* Dall.[57]
Argobuccinum oregonense Redf.[57]
Bela tabulata Cpr.[57]
Boreotrophon gracilis Perry.[57]
Boreotrophon stuarti Baird.[57]
Buccinum strigillatum Dall.[57]
Calliostoma costatum Mart.[57]
Caesia fossata Gld.[57]
Caesia perpinguis Hds.[57]
Calyptraea fastigiata Gld.[57]
Chrysodomus phoeniceus Dall.[57]
Chrysodomus tabulatus Baird.[57]
Columbella gausapata Gld.[57]
Epitonium hindsii Cpr.[57]
Lacuna vincta Mtg.[57]
Lepeta concentrica Midd.[57]
Margarites pupilla Gld.[57]

[57] Species still living.

FIG. A.

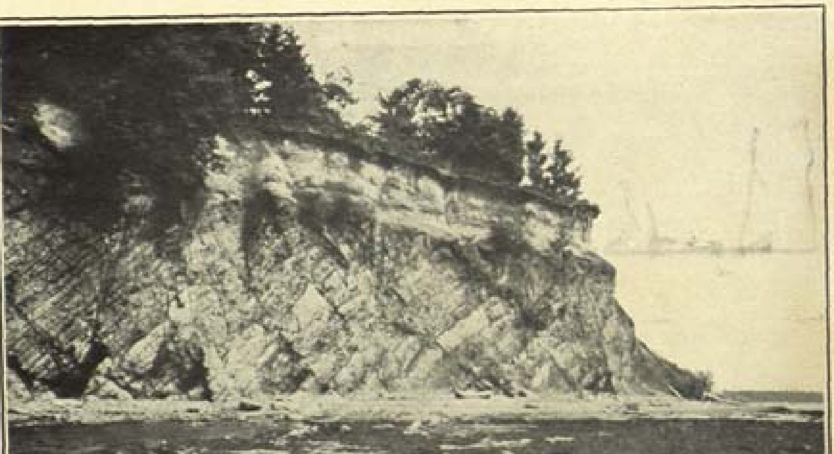


FIG. B.

FIG. A. Glacial grooving of Vancouver greenstone-diorites at entrance to Victoria Harbor, Vancouver Island.

FIG. B. Seattle shale (Astoria series) overlain by Pleistocene sands, Ilwaco. Washington.

Natica clausa B. & S.[57]
Nucella decemcostata Midd. (*Purpura lima* auct.).[57]
Nucella lamellosa Gmel. (*Purpura crispata* Chem.).[57]
Nucella saxicola Val.[57]
Olivella biplicata Sby.[57]
Olivella pedroana Conr.[57]
Polinices draconis Dall.[57]
Polinices pallida B. & S.[57]
Puncturella galeata Gld.[57]
Purpura foliata Gmel.[57]
Sipho halibrectus Dall.[57]
Solariella cidaris A. Ad.[57]
Trichotropis cancellata Hds.[57]
Tritonalia lurida Midd.[57]
Tritonifusus rectirostis Dall.[57]
Turris perversa Gabb.[57]
Turris smithi Arn.

BRACHIOPODA:
Hemithyris psittacea L.

ECHINODERMATA:
Scutella oregonensis Clark.

THE SAANICH FORMATION (PLEISTOCENE).

Benching the Oligocene and glacial deposits at Alki Point and Bainbridge Island in Puget Sound, filling glacial depressions at various points north of Victoria on the Saanich Peninsula of Vancouver Island, and terracing the length and breadth of the Straits of Georgia notably the Sucia Islands is a raised beach deposit for which the writers propose the name Saanich Formation. This formation carries numerous mollusca, usually species now living in adjacent waters, but others extinct or like *Pecten islandicus* Müller, *Cardium decoratum* Grnk. and *Mya arenaria* L. are now native only off the Alaska coast or at other arctic points. In this respect it resembles the lower San Pedro fauna which contains species now confined several hundred miles or more northward.

Overlying the marine deposits in several glacial hollows on the Saanich Peninsula are peat and marl beds containing numerous freshwater shells, the species being identical with those found in adjacent lakes. It appears that after the Post-Saanich elevation

[57] Species still living.

these hollows were filled by freshwater lakes and gradually silted up as Swan Lake and others on the Saanich peninsula are yet doing.

With the Saanich formation are tentatively included the widespread raised beaches on the west coast of Oregon and Washington containing marine shells at Cape Blanco, Bandon, and Newport in the former state and at Bay Center in the latter. Reagan[58] mentions the occurrence of marine shells in Pleistocene deposits at Beaver Prairie on the Olympic Peninsula, but the locality here is an old kitchenmidden.

Partial List of Species in the Saanich Formation (Pleistocene) of Puget Sound and the Straits of Georgia.

PELECYPODA:

Cardium corbis Mart.
Cardium decoratum Grnk.[59]
Macoma calcarea Gmel.
Macoma inquinata Desh.
Macoma nasuta Conr.
Mya arenaria L.[59]
Mya truncata L.
Mytilus edulis L.
Paphia staminea Conr.
Paphia tenerrima Conr.
Pecten islandicus Müll.[59]
Pecten hastatus hericeus Gld.
Saxicava arctica L.
Saxidomus giganteus Desh.
Serripes groenlandicus Gmel.
Schizothaerus nuttalli Conr.

GASTEROPODA:

Buccinum percrassum Dall.
Natica clausa B. & S.
Nucella lamellosa Gmel.
Polinices lewisii Gld.

GEOLOGICAL HISTORY.

The Coast Range of Oregon and the Willamette Valley.

The Coast Range, Willamette Valley, and Cascade Range of Oregon as has been intimated in the discussion of the Arago lavas were apparently built up during Eocene time as a gently westward

[58] Geological Papers Kans. Acad. Sci., 1908, p. 229.
[59] Species now native only to northward.

FIG. A.

FIG. B.

FIG. A. Steilacoom gravels (outwash of Vashon drift), prairie between Gate and Olympia, Washington.

FIG. B. Glacial deposits at south end of Marrowstone Island, Port Townsend, Washington.

sloping floor of successive basaltic flows and tuffs. In the Cascade Mountains intercalated sediments are reduced to a minimum but farther to the west and south they apparently replace more and more the igneous materials. With the close of the Tejon this floor was elevated into the form of a plateau with a synclinal sag at the present position of the Willamette Valley. At the opening of the Astoria period of sedimentation an arm of the sea extending up the Willamette Valley at least as far as Eugene connecting across the Range at Wren and Blodgett but it was not until the Seattle Epoch that the Coast Range was completely submerged by the load of igneous and sedimentary detritus piled upon it, for at many points on the west flank particularly near Nehalem and Tillomook Harbors the Seattle beds rest directly on the Eocene with the lower Astoria (San Lorenzo) lacking. Following this, western Oregon was elevated and except for an embayment of the Monterey sea which extended up the Columbia River and southward to the Tualatin Valley west of Portland, no later sediments have been deposited inland from the extreme western border. It is probable that the coast line has stood near its present position during much of late Tertiary time owing to the existence of an important fault paralleling the coast for many miles. Elevations on the east side of this fault have resulted in the removal of all the later and much of the early Tertiary deposits and submergences on the west side have carried the successive deposits even deeper beneath the sea.

Much has been written of the continuity of the Willamette Valley with the geosynclinal trough of the Great Valley of California, but facts do not bear this out. The Willamette Valley is the result of the differential erosion of soft shales and sandstones compared with the basalts which flank it. It is underlain at no great depth by Eocene deposits, igneous and sedimentary, which frequently stand up as monadnocks through the thin veneer of fluvial deposits and alluvium. The so-called "Willamette Sound" either refers to the Oligocene embayment or to the fluvial deposits in the Willamette Valley above Oregon City where a late Tertiary basalt flow impinged in passing down the lower Willamette and Columbia Rivers and temporarily dammed back the Willamette River.

The Chehalis Valley and Southwestern Washington.

The geologic history of this district during the Tertiary has been: *first* the deposition of the Tejon series chiefly as an estuarine deposit but with some associated lavas, mostly basalts; *second* the deformation of Tejon by folding in a west-east or northwest-southeast direction; *third* the successive deposition of the Astoria Series, and the Monterey, Empire, and Merced formations; *fourth* the final elevation of the Olympic and Cascade Mountains in Pliocene time and the resultant faulting, prevailingly in an east-west or north-south direction, of all the Tertiaries of southwestern Washington into a jumble of westward-dipping monoclinal blocks. Except locally in the proximity of faults, folding of the Oligocene and later strata of Washington is almost unknown.

The Tertiaries of the Periphery of the Olympic Complex.

The succession of events about the periphery of the Olympic complex is similar to that of southwestern Washington, except that the Tejon is very largely absent and the folding which succeeded it has left no record. On the west coast several isolated areas of Tertiary rocks have been faulted down into the Cretaceous, and thus preserved. A fault which requires special mention in this connection is the one which marks the north boundary of the Olympic Mountains, extending from the mouth of the Soo-es River south of Cape Flattery to Lake Crescent and the head of S'quim Bay an unbroken distance of more than eighty miles. On the south side except at the terminii all the adjacent rocks are pre-Tertiary. To the north lies the great monocline of northwestward-dipping Oligocene beds. It is probable that a second fault paralleling this lies in the trough of the Straits of Fuca else it is difficult to explain that remarkable topographic feature. The structure of the gently seaward-dipping Tertiary rocks of the southwest coast of Vancouver Island may also be readily explained by an assumption that such a fault exists.

Puget Sound is probably a pre-Pleistocene valley of erosion filled by glacial debris. It has been regarded as a structural depression,

but if this is true it is difficult to explain why all the Tertiary and older rocks exposed about its borders or at various points in it form an integral part of a series of northward- or southward-dipping fault blocks which cross its major direction at right angles.

Notes on the Geological Formation Names Applied to the Tertiary of the North Pacific Coast.

During his work in 1911 and 1912 the junior writer made a special endeavor to visit as many as possible of the type-sections of the formations described on the North Pacific Coast and data are at hand to decide the age and status of practically all, as shown on the accompanying table. Those not already discussed may be noted chronologically.

Thos. Condon, in Cope, 1880, "Corrections of the Geological Map of Oregon."[60] The Astoria shales and *Solen* beds have already been considered in connection with the identity of the Astoria Series.

C. A. White, 1888, 1899, "On the Puget Group of Washington Territory"[61] and "The Mollusca of the Puget Group."[62] Broadly speaking the Puget Group is the equivalent of the Tejon Series. It was described as a freshwater deposit, but this is hardly true. While molluscan remains of any kind are generally scarce, several species described as freshwater forms are well-known marine Tejon species. Exactly how much of the Tejon is represented by the Puget is somewhat uncertain, however, and will continue to be so until the various floras are described and the species characteristic of the different portions of the Tejon become known. The Pierce County coal field where the Wilkeston section first described by White is located, represents about 14,700 feet of beds. The lowest 2,000 feet at the Fairfax and Montezuma mines evidently belong to the Chehalis formation judging by the flora. The upper 10,000 or 12,000 feet of beds (Carbonado, Wilkeston and Burnett formations) are certainly later and probably represent the Olequa. The beds on the Duwamish River near Allentown, eastward to Newcastle and

[60] *Am. Nat.*, XIV., 1880, p. 457.

[61] *Am. Jour. Sci.* (3d ser.), XXXVI., 1888, pp. 443–450.

[62] Bull. 51, U. S. Geol. Sur., 1889, pp. 49–63.

Squak Mountain, and southward to Green River, so far as palæobotanical evidence goes are of Chehalis age. Those at Bellingham appear to be younger, though more than one horizon may be represented. In any event the continued use of the name Puget is very misleading since the Upper Puget, so-called, is earliest Tejon (Chehalis), and the Lower Puget is later Tejon.

A. C. Lawson, 1894, "Note on the Chehalis Sandstone."[63] This formation redefined has already been considered as a division of the Tejon.

J. C. Merriam, 1896, "Note on Two Tertiary faunas from the Rocks of the south coast of Vancouver Island."[64] The section between Muir and Coal Creeks west of Sooke where Dr. Newcombe collected for Merriam in the early 90's, and courteously accompanied the junior writer in 1912, is recognized as the type of the Sooke formation. Dr. Merriam states that he never intended to name a Carmanah Point formation but the name has passed into the literature. The beds at this point are San Lorenzo shales overlain unconformably by Monterey conglomerate in the cliff beneath the lighthouse. Dr. Newcombe's collection came from the San Lorenzo shales, from Sooke boulders in the Monterey, and from the Monterey itself. The list should be expurged. The one quoted from Dall was derived from the San Lorenzo beds at Bonilla Point; it requires some revision.

W. H. Dall, 1898, "A Table of the North American Tertiary Horizons Correlated with One Another and with Those of Western Europe with Annotations."[65] The "foraminiferal shales . . . conformably underlying the Tunnel Point beds at Coos Bay, Oregon" contain a characteristic San Lorenzo fauna. The portion of the Tunnel Point beds adjacent to the "foraminiferal shales" represent a sandstone phase of the San Lorenzo. However, the bulk of the type section and the beds from which the fauna listed by Dall[66] came are of Empire age being separated from the main Empire

[63] *Am. Geol.*, XIII., 1894, p. 436.

[64] *Bull. Dept. Geol. Univ. Cal.*, II., 1896, pp. 101–108.

[65] 18th Ann. Rept. U. S. Geol. Sur. (II), 1898, pp. 323–348.

[66] Prof. Paper 59, U. S. Geol. Sur., 1909, p. 15.

syncline by faulting. An angular unconformity marked by Pholas-borings may be observed in a niche of the seacliffs which form the type-section of the Tunnel Point beds.

The *Aturia* bed at Astoria lies in the Seattle formation. As *Aturia angustata* ranges through the Astoria series and Monterey formation up and down the Pacific Coast, its value as an index-fossil of a single horizon is doubtful. The term "Astoria sandstone" appears to have been intended to cover Condon's *Solen* Beds at Astoria as well as the sandstones intercalated with the Astoria shales in the steep bluffs behind the town.

Mytilus beds; based on a locality at the north end of Shoalwater Bay (more properly Willipa Harbor), Washington, containing *Mytilus condoni* Dall = *M. middendorffi* Grnk. This is the Empire sandstone.

Coos Conglomerate, basal Merced conglomerate overlying the Empire beds at Coos Bay, Oregon. This is not the Coos Group of Vermont geological literature which is Palaeozoic.

J. S. Diller, 1896–1903, "A Geological Reconnaissance in Northwestern Oregon";[67] "Roseburg Folio," U. S. Geological Survey, 1898; "Coos Bay Folio," U. S. Geological Survey, 1901; "Topographic Development of the Klamath Mountains";[68] "Port Orford Folio," U. S. Geological Survey, 1903. The Arago is recognized as a division of the Tejon. Its subdivisions, the Pulaski and Coaledo, appear to be of interest chiefly to the coal geologist. The Tyee sandstone from the fauna at Basket Point on the Umpqua River is probably the same horizon as is also the Umpqua formation. The Wilbur tuff is a lithologic phase of the Arago, a type of rock not uncommon on the North Pacific Coast where fossiliferous beds rest upon basic igneous flows and tuffs.

The areas of Oakland limestone are so small that in the absence of a recognizable fauna it can only be considered as a local division. If post-Eocene in age, as supposed, these may represent isolated San Lorenzo areas similar to those flanking the Willamette Valley.

The relations of the Empire formation have already been con-

[67] 17th Ann. Rept. U. S. Geol. Sur., 1896, pp. 441–520.
[68] Bull. 196, U. S. Geol. Sur., 1902, pp. 30–31.

sidered. To this horizon are referred the lower 475 feet of the Cape Blanco beds. The upper 75 feet, argillaceous sands with some calcareous nodules, are unconformable on the Empire beds and form the base of the Elk River Formation, here referred to the Upper Pliocene.

Willis and Smith, 1899, "Tacoma Folio," U. S. Geological Survey. Three divisions of the Lower Puget (middle and perhaps upper Tejon), the Carbonado formation, Wilkeston sandstone, and Burnett formation are named. So far no palæontological evidence has been advanced to insure their recognition beyond the limits of the Pierce County coal field.

R. Arnold, 1906, "A Geological Reconnaissance of the Olympic Peninsula."[69] The use of the Arago in place of Crescent, and Monterey in preference to Clallam has already been discussed. Other beds on the north coast of Washington mapped with the Clallam as undifferentiated Oligocene-Miocene are now assigned to one horizon or another of the Astoria series.

The Quinaielt formation is divided on palæontological grounds between the Empire and Merced formations.

A. B. Reagan, 1908, "Some Notes on the Olympic Peninsula."[70] Most of geological data in this paper are adopted from the one by the senior writer just mentioned. The Hoko River Pliocene, so-called, is an area of Monterey sandstone and conglomerate uncomformable on the Astoria series. The Raft River Pliocene contains a small but characteristic Empire fauna. The description of the Quillayute formation is based on the glacial filling of the valley of the Quillayute River. If Reagan had visited the locality from which the fossils he describes from the Quillayute were brought by the Indians, he would have found it to be about two miles from the Devils Club swamp where he says they occur, and the formation lithologically very different from what he describes. It is typical Empire sandstone.

C. E. Weaver, 1912, "A Preliminary Report on the Tertiary Palæontology of Western Washington."[71] Cowlitz formation; the

[69] *Bull. Geol. Soc. Am.*, XVII., 1906, pp. 451–468.
[70] Geol. Papers, Kans. Acad. Sci., 1908, pp. 131–238.

TABLE OF CORRELATION OF THE FORMATION NAMES APPLIED BY VARIOUS AUTHORS TO THE TERTIARY HORIZONS OF THE NORTH PACIFIC COAST.

	Formation.	Condon, 1880.	Merriam, 1896.	Dall, 1898.	Diller, 1896–1903.	Willis and Smith, 1899.	Arnold, 1906.	Reagan, 1908.	Weaver, 1912.
Pleistocene	Saanich								
	Vashon drift					Vashon drift			
	Admiralty till					Admiralty till		Quillayute (type section)	
Pliocene	Elk River				Elk River Cape Blanco (in part)				
	Merced			Coos conglomerate	Coos conglomerate		Quinaielt	Quinaielt (in part)	
Miocene	Empire	*Solen* beds (in part)		*Mytilus* bed Empire Tunnel Point (in part)	Empire Cape Blanco (in part)			Quinaielt (in part) Quillayute (fauna only) Raft River	Montesano Chehalis (in part)
	Monterey	*Solen* beds (in part)	Carmanah Point (in part)	Astoria sandstone (in part)			Clallam	Hoko	Chehalis (in part) Wahkiakum (in part) Blakely (in part)
Oligocene	Astoria: Twin River	Astoria shale		Astoria s. s. (in part) Astoria shale *Aturia* bed			Mapped with Clallam as undifferentiated Oligocene-Miocene	Clallam	Blakely (in part) Lincoln Creek (in part)
	Astoria: Seattle								Wahkiakum (in part) Blakely (in part) Lincoln Creek (in part)
	Astoria: San Lorenzo	*Solen* beds (in part)	Carmanah Point (in part)	Tunnel Point (in part) Foraminiferal shale	Oakland limestone?				
	Sooke		Sooke	Sooke					
		White, 1888–9.	Lawson, 1894.						
Eocene	Arago			Arago	Umpqua {Wilbur, Tyee} Arago {Coaledo, Pulaski}		Crescent tuffs	Crescent tuffs	Tejon
	Tejon {Olequa, Chehalis}	Puget Group	Chehalis sandstone	Puget Group		Lower Puget {Burnett, Wilkeston, Carbonado} Upper Puget			Lincoln Creek (in part) Cowlitz

fauna of the beds on the Cowlitz River below the mouth of Drew Creek is identical with that at Chehalis and Centralia in the lower Tejon (Chehalis formation).

Lincoln Creek formation; this is very vaguely defined. The area shown on the map comprises two different things, Chehalis beds underlying the basalts of the Balch syncline, and a conformable sequence of a late phase of the San Lorenzo formation and an early phase of the Seattle. The fauna listed appears to have come from the basal San Lorenzo beds at Oakville about fifteen miles away. The equivalent beds of Sinclair Inlet are apparently lower San Lorenzo, and those of the Cape Flattery section, like most of the rocks on the west coast of the Olympic Peninsula mapped by Weaver as Lower Miocene, are Cretaceous.

"Tejon formation." The exact use of this formation name in Washington is uncertain. The fauna listed appears to have come from the Olequa beds near Little Falls and on Coal Creek above Stella. If the term Tejon is used in the broad sense that it is by the writers then the reasons for separating the Cowlitz formation which contains a fauna much more closely allied to that at Fort Tejon in California are not apparent. If it is used in a restricted sense for the Olequa beds then it is obviously misapplied.

Blakely formation; this name seems to be intended to cover all the Oligocene-Lower Miocene deposits of the Puget Sound and north coast of Washington. The type-section on Bainbridge Island is the exact equivalent of the Astoria Series as recognized by the writers.

Wahkiakum formation; the Oligocene-Lower Miocene of southwestern Washington. The type-section is Monterey sandstone but many of the fossils listed came from the Astoria beds on Skamokawa and Grays Rivers.

Chehalis formation; the type section is Monterey and Empire, and the fossils listed a mixture of the shale faunas of the two.

Montesano formation; apparently intended as a local name for the Empire sandstone.

THE NOMENCLATURE OF MINERALS.

By AUSTIN F. ROGERS.

(*Received May 14, 1913.*)

About five thousand mineral names are in use or have been proposed.[1] These names are, of course, mainly varieties and synonyms. Many of them have been discarded and are gradually disappearing from the literature. Even some of the Germans are dropping such names as *kupferglanz* and *eisenkies* and are using the international names, chalcocite and pyrite in this instance. Thanks to the fifth edition of Dana's "System of Mineralogy" the synonymy has been pretty thoroughly worked out and most of the names used for the distinctive minerals are well established.

Though there are about five thousand mineral names, there are not more than a thousand distinctive minerals.[2]

The distinctive minerals are usually called "simple minerals," "definite minerals," "mineral species," or "definite mineral species." It is necessary to use some such term, for the word mineral is used (1) as a general term for the inorganic constituents of the earth's crust, (2) in a popular way for a metallic substance of commercial value that is mined or quarried and (3) in a restricted sense for a natural inorganic substance of definite chemical composition.[3]

The term most used is "mineral species," borrowing a biological term. In this connection it is interesting to note that a binominal

[1] The most complete list of mineral names available is found in the "Mineralogisches Taschenbuch" of the Vienna Mineralogical Society published at Vienna in 1911.

[2] In Dana's "System" and Appendices up to the year 1909, 951 minerals are given. In Groth's "Tabellarische Uebersicht der Mineralien" (1908) there are 829. In the "Mineralogisches Taschenbuch" of the Vienna Mineralogical Society (1911) there are 972 (including 22 hydrocarbons not given by Dana and Groth). So the number of distinctive minerals is, in round numbers, 1,000.

[3] For an interesting discussion of the use of the word mineral see an article by J. W. Gregory, *Trans. Institution of Mining Engineers*, 1909.

nomenclature like that now used for plants and animals was at one time used for minerals. In the first (1837) and second (1844) editions of Dana's "System of Mineralogy" binominal names[4] were given along with the usual names, mostly ending in *-ite*. Thus barite was known as *Baralus ponderosus* and celestite as *Baralus prismaticus*. The genus *Baralus* also included witherite, strontianite, and barytocalcite. Classes and orders were also recognized. The classification used then was the natural history classification of Werner and Mohs based upon external characters.

This gradually gave way to the chemical classification of Berzelius and the Swedish chemists. In the third edition (1850) of Dana's "System" the chemical classification was adopted and the binominal names, even as synonyms, were rejected.

A mineral species is a mineral with definite chemical composition and distinctive crystal form (or crystalline structure). "Definite" must be interpreted in the light of isomorphism, including mass-effect isomorphism first recognized by Penfield.[5] It is also necessary to recognize solid solutions of a kind different from isomorphism.[5a] Pyrrhotite,[6] for example, is a solid solution of sulfur, S, in ferrous sulfid, FeS. Nephelite,[7] is a solid solution of $NaAlSiO_4$, $KAlSiO_4$ and $NaAlSi_3O_8$, of which only the first two are isomorphous.

Crystal form must also be used in defining a mineral species for polymorphous minerals are distinct and are often strikingly different in physical properties as in the extreme case of diamond and graphite. Some of the dimorphous minerals have distinctive names (*e. g.*, calcite, aragonite) but there is a tendency to use a prefix before the first known mineral for the dimorphous form. Thus we have clinozoisite, paralaurionite, pseudowollastonite, metaboracite,

[4] These binominal names were first suggested by Dana in an article in the fourth volume of the *Annals of the New York Lyceum*.

[5] That is, in large molecules dissimilar elements or groups may replace each other. See *Amer. Jour. Sci.* (4), Vol. 7, p. 97, 1899.

[5a] Küster (*Zeit. für phys. Chem.*, Vol. 17, p. 367, 1895) maintains that a distinction should be made between solid solutions and isomorphous mixtures.

[6] Allen, Crenshaw, and Johnston, *Amer. Jour. Sci.* (4), Vol. 33, p. 193, 1912.

[7] Bowen, *Amer. Jour. Sci.* (4), Vol. 33, p. 49, 1912.

and neotantalite for the dimorphous forms of zoisite, laurionite, wollastonite, boracite, and tantalite respectively.

Since the rise of colloidal chemistry the question of names for colloidal or amorphous minerals arises. Recently names have been proposed for a few of the naturally occurring amorphous numerals. These substances can hardly be excluded from the list of mineral species as they are definite in composition, unless we insist that a mineral must be crystalline in character. To obviate this difficulty Niedzwiedzki[8] has proposed the term *mineraloid* for the natural amorphous substances. Among examples of colloidal minerals or mineraloids are the following: ostwaldite = colloidal AgCl (buttermilcherz); jordisite = colloidal MoS_2; α-kliachite = colloidal $Al_2O_3 \cdot H_2O$; β-kliachite = colloidal $Al_2O_3 \cdot 3H_2O$; ehrenwerthite = colloidal $Fe_2O_3 \cdot H_2O$. The term sulfurite has been proposed for amorphous sulfur and metastibnite for amorphous antimony sulfid. Fortunately there are very few amorphous minerals which are definite enough to be recognized as distinct mineral species[9] but the application of colloidal chemistry to mineralogy will probably increase the number in the future.

Names are used not only for definite chemical compounds, which are often end members of isomorphous series, but also for isomorphous mixtures such as olivine, rhodolite, epidote, and pisanite; for double salts such as dolomite and monticellite; for pseudomorphs such as martite, arkansite, and hampshirite; for mechanical mixtures such as californite and azurlite; for semiprecious or ornamental stones such as bonamite and satelite; for artificial substances such as alite, cementite, silver-analcite, soda-leucite, and carnegieite; for group names such as orthoaugite, clinoaugite, glaucamphibole; and for numerous varieties based upon crystal habit (*e. g.*, adularia), structure (*e. g.*, pholerite, nemalite), color (*e. g.*, melanite, hiddenite, kunzite), unusual optical properties (*e. g.*, isomicrocline, neocolemanite), and variations in chemical composition due either to impurities, (*e. g.*, johnstonite) or to isomorphous replacement (*e. g.*, cuprogoslarite, paravivianite, titanaugite). Varietal names are

[8] *Centralblatt für Min. Geol. u. Pal.*, 1909, p. 661.

[9] Of the more common minerals only opal, bauxite, psilomelane, and allophane are amorphous.

rarely consistent or logical for they are not usually coördinate and not uniform for the various minerals. In the earlier editions of Dana's "System" varieties were greatly subordinated but in the fifth and in the current sixth edition varieties are again given prominence. As Miers[10] has emphasized, the non-essential properties of mineral have received too much attention. The recognition of this fact will naturally lead to the supression of varietal names as far as possible. While often convenient their use tends to confusion. For example iron-bearing sphalerite has been called marmatite. A sphalerite from Breitenbrunn, Saxony containing eighteen per cent. of iron was named cristophite. Where draw the line between marmatite and cristophite? Sphalerite usually contains more or less iron. If the iron content is notable or needs to be emphasized let it be called ferriferous sphalerite. No special name is necessary.

Names should serve two purposes, which are more or less distinct, namely convenience and accuracy. A name serves a convenient purpose for distinguishing a particular variety or kind of mineral found at a certain locality or one with striking properties found at several localities. But there are so many variations in the properties of minerals that the names multiply too rapidly. Accuracy is not attained for it is very difficult to correlate the different varieties and to define them accurately.

Isomorphism plays a very prominent part in explaining the chemical composition of minerals for many minerals are isomorphous mixtures of two end members. The gaps in isomorphous series are gradually being filled in.

The only satisfactory way of simplifying mineralogical nomenclature is, in my opinion, to name a mineral by its predominant molecule of the isomorphous series to which it belongs. If the mineral is described and named before the isomorphous relations are understood the name still stands for the predominant molecule present. The other names used for varieties, isomorphous mixtures, pseudomorphs, etc., should be discarded, except in a few cases to be mentioned later. Isomorphous mixtures may be indicated by qualifying terms, *e. g.*, ferriferous sphalerite instead of marmatite. The

[10] "Mineralogy," p. 2.

same method can be used with varieties. Thus we can use the term fibrous brucite instead of nemalite.

Such names as soda-orthoclase, natroalunite, ferrogoslarite, and manganocolumbite are ambiguous. Soda-orthoclase may mean an orthoclase in which a portion of the potassium is replaced by sodium or it may mean the sodium compound corresponding to orthoclase. The best method is to use a distinctive name for the monoclinic feldspar in which sodium predominates molecularly over potassium. For such a mineral, which has been found at several localities, Schaller[11] has proposed the name barbierite after the French chemist, Barbier. Note the inconsistency in these compound names. Ferrogoslarite is an iron-bearing zinc sulfate while manganocolumbite is a manganese niobate isomorphous with ferrous niobate. It might be well to restrict these compound names to artificially prepared members of isomorphous series not yet found in nature. Thus we could use the term soda-anorthite instead of carnegieite. The names silver-analcite, soda-leucite, zinc-römerite are examples.

If my suggestions are adopted a number of mineral names will be discarded. Embolite will be either cerargyrite (chlorargyrite) or bromyrite. Petzite will be auriferous hessite. Pisanite will be either cupriferous melanterite or ferriferous boothite. Hyalophane will be barium-bearing orthoclase. Mesitite will be ferriferous magnesite. Nigrine will be ferriferous rutile.

On the other hand, a few new names or resurrected old names will be necessary. Thus the name montebrasite would be resurrected for the basic lithium aluminum phosphate which is isomorphous with amblygonite, lithium aluminum fluo-phosphate. Very few new names will be necessary for synonyms and varieties can often be elevated to the rank of distinct mineral species.

Some exceptions to my rule should be made. The isomorphous mixtures of three or four common and important mineral groups now have distinctive names which should be retained. Thus we have oligoclase, andesine, labradorite, and bytownite in the plagioclase group. Olivine is a convenient name for the isomorphous

[11] *Amer. Jour. Sci.* (4), Vol. 30, p. 358, 1910.

mixture of magnesium and iron orthosilicates but the names hyalosiderite and hortonolite in the olivine group are hardly necessary. Epidote is an isomorphous mixture of basic calcium aluminum orthosilicate, clinozoisite, and basic calcium iron orthosilicate, not yet found. Hypersthene is an isomorphous mixture of magnesium metasilicate, enstatite, and ferrous metasilicate, not yet found. It might be well as assign arbitrary limits to olivine, hypersthene, and epidote. This must be done if the names are to be accurate. Dana uses the name hypersthene for orthorhombic pyroxene with ferrous oxid content of over ten per cent. For these various isomorphous mixtures arbitrary divisions similar to those used in the quantitative classification of igneous rocks might be used.

Are the names of mineral species to be arbitrary or can any system of giving names be used? Leaving out the binomial nomenclature there are three possibilities to consider.

1. *Chemical Names.*—As minerals are substances of definite chemical composition purely chemical names will appeal to some as being the simplest and best. But minerals are often complex in composition and the chemical names would be long and cumbersome. While accurate they are not convenient. Moreover the name of a mineral connotes certain physical properties. Calcite is more than calcium carbonate. It is calcium carbonate with certain definite physical properties. The chemist would obviate this difficulty by using the term α-$CaCO_3$ for calcite and β-$CaCO_3$ for aragonite. Except for the elements, perhaps, distinctive names are preferable to chemical names.

2. *Arbitrary Names.*—The names used at present are derived from the locality at which the mineral was first found, from the name of the person who discovered or described the mineral, or they are based upon some prominent physical or chemical characteristic. They are arbitrary and without system except that most of them end in *-ite* (from the Greek and Latin *-itis* or *-ites,* which was added to a word signifying a quality, use, or locality of the mineral). Among other terminations are *-ane, -ine, -ase, -ote, -ole,* and *-ome* while older names include galena, quartz, garnet, etc. Some of the names have a chemical significance but even they are

in part arbitrary. Cuprite might have been applied to any copper mineral but it is arbitrarily used for cuprous oxid.

3. *Combined Chemical and Arbitrary Names.*—Still a third method is an attempt to combine the chemical names with arbitrary root-names. This method is used to some extent at present. We have such names as natramblygonite, plumbojarosite, and manganocolumbite, for distinctive minerals. As emphasized before these names are ambiguous and so are objectionable. In fact all such compound names should be discarded, except as indicated above. For varieties, qualifying chemical terms can be used. For example we can use the term ferriferous goslarite instead of ferro-goslarite. For distinctive minerals such as natramblygonite, plumbojarosite, and manganocolumbite it is preferable to use distinctive names.

In a recent paper entitled "Suggestions for Mineral Nomenclature,"[12] H. S. Washington proposes a new system of mineral nomenclature. He uses as a root name for the acid radical of a mineral group the present name of a typical member of the group. This root name is modified by chemical terms to indicate the particular mineral. For the apatite group the root name is *apatate*. Apatite is calcium phosphapatate, pyromorphite is lead phosphapatate, while mimetite is lead arsenapatate. The root name for the sphalerite group is *sphaleride*.[13] The sulfids of this group are called sulsphalerides, the selenids, selsphalerides, and the tellurids, telsphalerides. Sphalerite itself is called zinc sulsphaleride, metacinnabar, HgS, is mercury sulsphaleride while tiemannite, HgSe, is mercury selsphaleride and coloradoite, HgTe, is mercury telsphaleride. Calcite is calcium calcitate, siderite is ferrous calcitate, and dolomite is magnesicalcium calcite. Forsterite is magnesium olivenate. Orthoclase is potassium adularate. Albite is sodium albate, etc.

Washington's proposed system emphasizes the isomorphous relations, but in my opinion that is about the only good point in its favor. As Washington himself admits, the names are barbarous and uncouth. Most of them are also long and cumbersome and so do not

[12] *Amer. Jour. Sci.* (4), Vol. 33, p. 137, 1912.

[13] The termination *-ide* is used for binary compounds and sulfo-salts while the termination *-ate* is used for the oxy-acid salts.

serve the purpose of convenience. For example, the name for the basic calcium phosphate for which I recently proposed the name voelckerite[14] would be something like calcium oxy-phosphapatate.

Arbitrary names I believe are preferable to names such as those proposed by Washington. My reasons are as follows:

1. Arbitrary names are stable; there is no necessity for change because of an incorrect analysis.

2. Any name of a new mineral that is proposed stands for the predominant molecule whatever its isomorphous relations may be.

3. Arbitrary names are more convenient than other names because they are shorter.

4. The present names are to a large extent retained and very few names will be necessary.

Most of the present names are so well established by long association that it will be almost impossible to substitute other names for them. The law of priority, with certain limitations,[15] holds in mineralogy as in zoölogy and botany.

Only the professional mineralogist would be apt to use Washington's system, but to him the arbitrary names are not objectionable.

There is one apparent objection that may be urged against my plan. A quantitative chemical analysis will often be necessary to place and name a mineral that is near the dividing line between two isomorphous compounds. This is unfortunate from the standpoint of determinative mineralogy but it is no real objection. It goes without saying that accuracy of definition is based upon accurate work which must often be quantitative in character. As Miers[16] says ". . . it cannot be too strongly impressed upon the student at the outset that scientific mineralogy is based upon accurate measurements and determinations."

There are several points to mention in connection with the recording of chemical analyses of minerals. I think it is well, as I have done in a recent text-book,[17] to record mineral analyses in the form of metals and acid radicals instead of the usual form of oxids. The

[14] *Amer. Jour. Sci.* (4), Vol. 33, p. 475, 1912.

[15] Dana, "System of Mineralogy," 6th ed., p. xliii, 1892.

[16] "Mineralogy," p. v.

[17] "Introduction to the Study of Minerals," New York, 1912.

present method is based upon antiquated notions dating back to electro-chemical theory of Berzelius. The ideal way would be to record the constituent elements. This can be done with haloids, sulfids, and sulfo-salts but not with the oxygen salts for there is no method of determining oxygen directly. If haloids or sulfids are combined with oxygen salts as in minerals of the apatite group there is decided advantage in recording percentages of the metals and acid radicals. In the silicates the acids and acid radicals are not known and it is necessary to use the ordinary oxids as in rock analyses.

In recording analyses it is well to give the molecular ratios of elements and acid radicals in addition to the percentage composition even if the purpose is not to establish a chemical formula.[18] This plan has been proposed for igneous rocks by Washington[19] but might well be extended to cover minerals. Murgoci[20] in an article on the classification of the amphiboles uses a tabulated list of the molecular ratios instead of the more usual percentage compositions.

My suggestions concerning mineral names are far from carried out at present. Out of Spencer's list[21] of about one hundred new mineral names proposed between the years 1907–10 approximately, not more than fifty-five can possibly be regarded as distinct mineral spaces. That is, forty to fifty names proposed within this short time are, in my opinion, practically useless. There are glendonite, pseudopirrsonite, and pseudostruvite, names for pseudomorphs. Fermorite, anemousite, spandite, and grandite are isomorphous mixtures. Spandite is an isomorphous mixture of spessartite and andradite, while grandite is an isomorphous mixture of grossularite and andradite. While these names may occasionally be convenient they only increase the difficulty of naming a mineral. The names are not exact for the limits are not defined. Azurmalachite, sefströmite, and leesbergite are mechanical mixtures. Alomite,

[18] The tables in Kemp's "Handbook of Rocks," 5th edition, pp. 171–177, will be found useful in converting percentage compositions into molecular ratios.

[19] *Amer. Jour. Sci.* (4), Vol. 10, p. 59, 1900.

[20] *Bull. Dept. Geol., Univ. of California Pub.*, Vol. 4, pp. 377 and 383.

[21] *Mineralogical Magazine*, Vol. 15, p. 415, 1910. For previous lists see ibid., Vols. 11, p. 323; 12, p. 378; 13, p. 363; and 14, p. 394.

bonamite, ricolite, satelite, and vredite are trade-names of semi-precious and ornamental stones. Aglaurite (orthoclase), bravoite (pyrite), hallerite (paragonite), cobaltocalcite (calcite), isomicrocline (microcline), loaisite (scorodite), neslite (opal), magnesium-pectolite (pectolite), pulleite (apatite), tawmawite (epidote) are simply varieties of the minerals indicated. Still other names are synonyms but these are often unavoidable.

The task of descriptive mineralogy is to establish and define the distinctive minerals or mineral species but the science is greatly handicapped by hundreds of varietal names which are worse than useless.

In conclusion let me urge that in the future new names be given to *bona fide* mineral species only and that distinctive names of varieties, pseudomorphs, and mixtures be discarded as far as possible.

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THE CHARACTER AND ADVENTURES OF MULADEVA.

By MAURICE BLOOMFIELD, Ph.D., LL.D.

(*Read April 18, 1913.*)

Any selection of Hindu fiction might fitly open with the only story that attempts a continuous account of Mūladeva's adventures, because Mūladeva is one of the very few figures in Hindu fiction that may be described as a "character." In general the personnel of Hindu fiction is made up of stock or lay figures. Such are, above all, the young prince, usually of ineffable beauty, virtue, strength and skill, who contrives to get himself separated from his happy home, and starts upon a career of adventure. This leads up to a union with a no less hyperbolically beautiful and virtuous princess. The hero, for his part, is liable to be carried off by a mettlesome horse into the wilderness, where his adventures begin. He is pretty sure to come upon the heroine in some unpleasant predicament, such as a prospective uncongenial marriage, or, when she is in some personal danger. *E. g.*, times without end, the hero saves the beautiful maiden from an infuriated elephant, usually by throwing his upper garment before the elephant's trunk.[1] Or, quite in the manner of St. George and the dragon, he saves the princess from a bloodthirsty Rākṣasa.[2] In the end he marries her, and she, incidentally, bestows her father's kingdom upon him.

Very frequently the prince is attended by a faithful friend, perchance the son of his father's chief minister. The two, as boys, had played in the sand together, that is, had made mud-pies together.[3] This friend is prone to display much heroism and self-sacrifice in behalf of the prince: he is a stock figure of the better sort. Simi-

[1] Kathāsaritsāgara 89; Story of Bambhadatta, in Jacobi's "Ausgewählte Erzählungen," p. 16, l. 19 ff.; "Story of Agaḍadatta," ibid., p. 71, stanzas 53 ff.

[2] Kathāsaritsāgara 79; Vetālapañcaviṅçati 5.

[3] Such a person is called in Sanskrit, pāṅsukrīḍita (Pariçiṣṭaparvan, p. 123; cf. Harṣa-Carita 1, Bombay edition, 1897, p. 17; in Pāli, paṅsukīlita (Jātaka 83 and 519); Mahāvāstu 3. 451; in Prākrit, paṅsukīliya, Jacobi's "Ausgewählte Erzählungen," p. 20, l. 16.

larly, the heroine has a faithful female friend, who is almost invariably the go-between, or love's messenger (*servus currens*) between herself and the hero. The lady, as a rule, takes the initiative, by look or act, in establishing relations with her lover-to-be.

Comfortably settled kings, in their maturer years, are also taken with a kind of "wanderlust," and roam in search of adventures.[4] Merchants and merchants' sons start on quests of trade and wealth; travel to a great distance; suffer ship-wreck; are rescued by dangerous sirens; are destroyed by them; or attain in the end marvelous prosperity. Holy men, gifted with supernatural powers, wander about; whensoever they are treated properly they secure the happiness of deserving lay persons. On the other hand, all sorts of rogues in the guise of holy men play tricks under the mantle of their sanctity, usually to meet with discomfiture and disgrace in the end. Faithful or faithless wives; noble or degraded courtezans; gamblers, thieves, and robbers are further instances of the stereotyped dramatis personæ of Hindu fiction. To a very considerable extent all these adventures are lifted to a higher plane of romanticism by the interference, or *deus ex machina* coöperation of supernatural beings: benign gods, magic-loving Vidyādharas, Yakṣas, and heavenly nymphs, called Apsaras. And all persons, divine or human, operate with supernatural agencies: magic objects that grant wishes, or perform wonderful acts; powerful charms; the forecast of dreams; the prophecies of holy men and women.

The adventures of all these personages contain as a rule no very continuous plots. They usually consist of a chain of salient, individual, romantic episodes, strung together, one after another. Quite frequently, one or the other of the happenings are in the nature of an anecdote, or prank, or trick which one person in the story plays upon the other. In this latter phase of fiction puns and riddles often play a part. The separate events of a story rarely unfold character, and do not necessarily contribute to such *dénouement* as the story may happen to have. There is the familiar boxing of story within story, and frequently the events told in one and the same story are really different events which merely overlap each other at some one point.

[4] See Prabandhacintāmaṇi, Tawney's Translation, pp. 12, 30, 42.

The real interest of Hindu fiction lies in the ingenuity, imaginativeness, and shrewdness of each unit of story-telling. Taken in bulk, these stories seem fairly to exhaust all the permutations which can be imagined to arise from the juncture of real or fictitious persons and things with the circumstances of time and place. Therefore, the individual motifs of story or fairy-tale, as found with other peoples, seem to hold a kind of mass-meeting on the great arena of Hindu fiction. As is well known, the ancient treasury of narrative which India pours out lavishly from the time of the Rig-Veda to this day, passed freely beyond the bounds of India. Not only the stories and fables of entire cycles, such as the Pañcatantra, or the 'Seventy Tales of the Parrot,' were exported bodily and taken over by other literatures, but numberless individual stories and individual story traits penetrated to the farthest ends of the earth. It is, at any rate, rather hard to find, in the rest of the world, fable or fiction traits of marked character which do not own to an Indian analogon; many a time they may, at least, be suspected to be of Indian origin. As a corollary to this last condition, nearly all the more important motifs are intensely repetitious in the Hindu narratives themselves, so that, as a matter of external experience, there are neither absolutely original fables or stories, nor absolutely original collections of such fables or stories.

With all this wealth of themes, and the clever way in which they are worked up, the Hindu story rarely goes beyond the limits of a sort of thin novelette. Real types of men and women are, as a rule, either wanting, or they are indicated by crude, sometimes contradictory delineation. The biography of Mūladeva, though dwelled upon with some insistence, is no exception to the rule; yet it fulfils to a certain extent more modern requirements as regards delineation of character. The stories told about him show more real sequence, closer interlocking of cause and effect than is customary in Hindu fiction.

The most important story of Mūladeva is preserved in Devendra's Vṛtti, a sort of commentary on the Jain text called the Uttarādhyāyana. Mūladeva, moreover, figures in an autobiographic episode of his own life, narrated by himself to a king in Kathāsaritsāgara

124, or at the end of the tenth book of the Bṛhatkathāmañjarī. Again, in the fifteenth 'Tale of the Vampire' (Vetālapañcaviñçati), he acts a Mephistophelic part in involving a princess in two marriages, arranged so trickily that it is hard to say which husband she really belongs to. Mūladeva figures occasionally in other stories; in addition, a lively tradition of a very variegated sort shows that he has fixed himself as a "character" in the imagination of the Hindu people through many centuries. Yet even Devendra's biography is rather in the nature of an impressionist sketch than a well-knit novel. Nor is his characterization in tradition as a whole by any means consistent: he has traits of Simplicissimus, Tyl Eulenspiegel, Cagliostro, Mephisto, and others. On the whole he is a rogue whose pranks have endeared him to the popular heart as a shifty, yet delectable figure, who may however, as in Devendra's story, occasionally be taken more seriously and padded out into a sort of hero.

The life history of Mūladeva fitly begins with his own name,[5] which seems to mean "Wizard," literally, "He who makes roots his divinity." Within the sphere of narrative in which Mūladeva figures, magic practices by means of roots are still as familiar as they were in the time of the Atharva-Veda.[6] Mūladeva is identified, next, with Karṇīsuta,[7] an author on the "Science of Thieving" (steyaçāstra-pravartaka). Karṇīsuta is said to be a Karaṭaka, some sort of gentile designation. In Daçakumāracarita, Apahāravarman, one of the princes who narrates his own adventures, himself a great scoundrel, tells how he decided to follow the way of Karṇīsuta, in order to teach the misers of a certain city the instability of wealth, by the simple device of stealing that wealth. At the end of the same story King Rājavāhana, after hearing Apahāra-

[5] Cited by the Kāçikā at Pāṇini 8. 2. 18.

[6] See Bloomfield, "The Atharva-Veda," General Index, p. 135[b]; Schmidt, Beiträge zur Indischen Erotik, pp. 739, 740; Prabandhacintāmaṇi (Tawney's Translation), p. 191.

[7] In the Lexicon called Hārāvalī, as cited by the commentary to Subandhu's Vāsavadattā; see Weber, "Indische Streifen," i. 383, note 2; Pavolini, GSAI. ix. 176; Meyer's translation of Daçakumāracarita, pp. 215, 244. Bālakṛṣṇa to Bāṇa's Kādambarī, in a roundabout fashion, also makes the same identification; see p. 621.

varman's rascally story, exclaims: "Why, you have gone Karṇīsuta's rough practices one better!"

Karṇīsuta goes, all told, by four names: (1) Mūladeva. (2) Mūlabhadra, perhaps, "Servant of Roots": the name is little more than an equivalent of Mūladeva. (3) Kalāṅkura, "Shoot of Accomplishments," that is, "Product of the 64[8] kalā's," or accomplishments, which belong to a *routiné* man of the world, or man about town, the typical nāyaka or "hero," a sort of "devil of a fellow," as he is sketched ideally and systematically in the scheme of the (to us) villanous Kāmaçāstras,[9] or "Love-Bibles" of India. (4) Karṇīsuta (Karṇīcuta[10]), and Karṇīputra, *i. e.*, "Son of Karṇī," a mother about whom we hear nothing, perhaps a courtezan. Else we should, according to Hindu models, expect a patronymic, rather than a metronymic. "Sons of maidens" (kumārīputra, kānīna) are well-known in Sanskrit literature, *e. g.*, VS. 30. 6; TB. 3. 4. 1. 2; Manu 9. 160, 172. In the two Vedic texts he typifies lust or pleasure (pramad, pramud).

This fourth name is similar to that of a frequently mentioned author of amatory literature, namely Goṇīputraka, Goṇikāputra, and Goṇikāsuta, *i. e.* "Son of Goṇī or Goṇikā." In the introduction to the Pañcasāyaka, "Five arrows (of the God of Love)," occurs the expression goṇīputraka-mūladeva-bhaṇitam, which looks for all the world as tho it meant "Mūladeva, the Son of Goṇī." In the same text Goṇīsuta and Mūladeva are mentioned once more, tho not side by side, as authorities; no other authors are mentioned at all. This also looks as tho the names were interchangeable, especially when we consider that the text is metrical and is liable to require differing quantities in a tetrasyllable; see Richard Schmidt, "Beiträge zur Indischen Erotik," p. 918 ff. The same author, p. 46, remarks

[8] Prabandhacintāmaṇi, p. 32, counts 72 accomplishments. So also Devendra, in the story of Agaḍadatta (Jacobi's "Ausgewählte Erzählungen"), stanza 22. See the list in Prabhāvaka-Carita (ed. Hīrānanda U. Sharmā), p. 132.

[9] Not so the Hindus. They regard the Kāmaçāstra as a legitimate Çāstra. *E. g.*, in the Prabandhacintāmaṇi, p. 63, Vātsyāyana's Kāmaçāstra is regarded as on a par with the three Vedas, the Raghuvança, and the Arthaçāstra (Kāuṭilīya) of Cāṇakya.

[10] This spelling due, perhaps, to Prākrit cuta "fallen," the standard expression for passing from a higher to a lower existence in the course of transmigration.

that Goṇīputra, and the like, are metronymics of an author whose real name is no longer known. It is probable, therefore, that Mūladeva, Karṇīputra, and Goṇīputra are one and the same man. In any case there is no occasion for scepticism as regards the identity of Mūladeva and Karṇīsuta. Bāṇa's Kādambarī (Peterson's edition, p. 19, l. 16) states that the Vindhya forest, like the story of Karṇīsuta, had its Vipulācala and Çaça. This is euphuistic indirection (vakrokti) for, "it had extensive mountains and was frequented by hares." The word for mountain is acala, and the word for hare is çaça. These two words figure in the Mūladeva legends as proper names of persons, and thus make out a mathematical equation between Mūladeva and Karṇīsuta.

So much for the name. As regards Mūladeva's character we may begin with his performances as an author. In Kṣemendra's Kalāvilāsa,[11] a satirical treatise on the foibles or tricks inherent in sundry walks of life, Mūladeva appears as the mentor (a sort of Viṣṇuçarman) of a young merchant's son, Candragupta. Mūladeva is designated as dhūrtapati, "prince of rogues." As such he is supposed to be a fit teacher of a young man of wealth and family, the point being that Mūladeva is best able to save a youth from the pitfalls of rogues and courtezans.

Next, he is, as was pointed out above, shining authority on kāmaçāstra: the Pañcasāyaka refers to him several times on intimate questions of the *ars amatoria*.[12] This is supported by a text called Çaktiratnakara, which deals with the secret cult of Durgā; he is there mentioned along with a set of kāmaçāstra authors which for the most part are cited elsewhere in this sphere of literature.[13] If my surmise is correct, that Goṇikāputra is no other than Mūladeva himself, his authority in this line of literature rises in the scale. Incidental mentions in literature show his adroitness not only in

[11] The text is published in the series Kāvyamālā, fascicles 1 and 2 (1886). An analysis of its contents is given by J. J. Meyer, in the Introduction to his translation of the Samayāmātṛkā, pp. xl ff. Cf. also Sylvain Lévi, "La Bṛhatkathāmañjarī de Kṣemendra," p. 11 (reprint). In Çukasaptati, 23, the merchant Candra entrusts, similarly, his son to the pander Dhūrtāmāyā, to teach him the wiles and tricks of bad women.

[12] See Schmidt, "Beiträge," pp. 50, 879, 919.

[13] See Charpentier, "Paccekabuddhageschichten," p. 58.

practices, but also in wise saws pertaining to love. In Kathāsaritsāgara 98 (Vetālapañcavinçati 24) a son encourages his widowed father to marry again, by means of a stanza composed by Mūladeva: "Who, that is not a fool, enters that house in which there is no shapely love eagerly awaiting his return, which tho called a house, is really a prison without chains?" A scholiast to the Saptaçataka of Hāla[14] cites a hemistich by Mūladeva of quite similar import: "It's no use anointing yourself with fragrant unguents, if you haven't a light-o'-love." In the 30th Story of the Parrot (Çukasaptati) two demons (piçācas) quarrel over the beauty of their respective wives. They catch hold of Mūladeva, who is to decide. He, thinking in his soul that both their she-devils are passing ugly, wriggles out with the verse: "To every lover in the world she alone seems charming that is his love; no other." The same riddle in Mahābhārata, Kathāsaritsāgara, and in the story of Oedipus; see Tawney's note to his Translation of Kathāsaritsāgara, i. 26.

Mūladeva is, however, not merely the theoretic academician of love. Tradition has him the practical promoter of love: wherever there be some beauty to conquer, either on his own account, or on the account of others, he pushes himself forward. More especially, in love-affairs of the shady sort, Mūladeva is the standard resort. Or, he plays the part of a mischievous devil in connection with illicit loves. Thus, as regards the last point, in the "Tales of the Parrot," 22, a farmer's wife who is in the habit of carrying him his dinner amuses herself with her paramour on the way. She deposits the dinner-kettle on the road, and Mūladeva puts in camel's meat. When her husband inquires suspiciously she, quick as a flash, answers: "Sir, I dreamt that you would be eaten by a camel, and have played this prank to nullify the omen." Another time, in an unsavory little story told in the Jain Āvaçyaka Niryukti, Mūladeva is on the road with a boon companion, a sort of *fidus Achates,* who is here named Kaṇḍarīka. They come across another traveler with his wife. When Kaṇḍarīka is smitten with the charms of the woman, Mūladeva tricks the husband.

Mūladeva climbs to the pinnacle of tricky mischief, as "lord of

[14] Cf. Weber, Das Saptaçatakam des Hāla, p. xxv.

rogues" in affairs of love, in the 15th Vampire story, as told in the Kathāsaritsāgara 89, or the 14th story in Çivadāsa's version of the same book. A young Brahman, Manaḥsvāmin, saves the life of a princess Çaçiprabhā from an infuriated elephant. The two young people, of course, fall madly in love with each other. Manaḥsvāmin, who is not eligible, goes to visit that master of magic, Mūladeva. Then that matchless deceiver places a magic globule into his mouth, and transforms himself into an ancient Brahman. He gives a second globule to Manaḥsvāmin, who turns into a beautiful maiden. And that prince of villains took him in this disguise to the judgment-hall of the king, the father of his lady-love, and said to him: "O king, I have only one son, and I asked for a maiden to be given him to wife, and brought her from a long distance. But now he has gone somewhere or other, and I am going to look for him; so keep this maiden safe for me, until I bring back my son; for you keep safe under your protection the whole world."[15] Needless to say, the king accepts the charge; gives Manaḥsvāmin as a companion to Çaçiprabhā; the two marry by the Gandharva rite; and Manaḥsvāmin is a woman by day and an ardent lover by night, using the simple device of putting in and taking out the magic globule.

In time the brother-in-law of the king gives his daughter, Mṛgāñkavatī, in marriage to the son of his minister. The princess Çaçiprabhā is invited to her cousin's marriage, and goes there with her ladies-in-waiting, including Manaḥsvāmin, wearing the form of a young maiden of exquisite beauty. The fresh bridegroom becomes distracted with love on beholding Manaḥsvāmin. There were no difficulty in his marrying Manaḥsvāmin as a second wife, but how can the king who has him (or her) in keeping for another husband, a Brahman's son, permit this marriage? It is decided to send the minister's son on a journey of six months; if, when he returns, the Brahman has not come back to claim the maiden, he may marry her also. Manaḥsvāmin, the trick-maiden, remains behind with Mṛgāñkavatī. The two girls become very affectionate, until finally

[15] The same ruse in similar stories, Çukasaptati 62; Pramati's adventure, Daçakumāracarita 5; Kathāsaritsāgara 7. 40-87; Vīracarita 8 (*Indische Studien*, xiv. 153 ff.).

the pupil of that master-rogue tells her: "I have a boon from Viṣṇu, by which I can at pleasure become a man during the night, so I will now become one for your sake." Then they elope before the minister's son, the husband of Mṛgāñkavatī, returns to claim the man-woman Manaḥsvāmin, who had been promised him as his second wife.

One should think that Mūladeva would be content with the impish mischief done so far. Not he. Again he takes on the guise of the old Brahman, turns his Leporello (who is this time called Çaçin) into a young Brahman, his supposed son, and goes to claim Manaḥsvāmin as his daughter-in-law from the fiduciary king. The latter is, of course, unable to deliver the goods, and, afraid of the feigned stern Brahman anger of Mūladeva, gives his own daughter Çaçiprabhā to Çaçin, by way of compensation.

Then Mūladeva takes this bridal couple to his own home, where Manaḥsvāmin meets them, and a fierce dispute takes place between the latter and Çaçin in the presence of that Mūladeva. Manaḥsvamin says: "This Çaçiprabhā should be given to me; for, long ago, when she was a maiden, I married her by the favor of the master (*i. e.*, Mūladeva)." Çaçin says: "You fool, what have you to do with her? She is my wife, for her own father bestowed her on me in the presence of the fire." The story cleverly dodges the decision of the dispute.

There is one charming story which Mūladeva narrates to the famous legendary king Vikramāditya, as illustrating the virtue and resourcefulness of a true wife. It is told in Kathāsaritsāgara 124, and, in a poor digest, in Bṛhatkathāmañjarī 10. 272 ff. As behoves the atmosphere of our hero, it is full of quips and pranks, but the joke is rather on Mūladeva, who narrates it with a sort of humorous self-persiflage. Mūladeva, in company with Çaçin, arrives at Pāṭaliputra, and, after some witty preliminary passes, full of give and take, with some of the inhabitants,[16] Mūladeva falls in love with a saucy Brahman's daughter who had shamed them by her wit. He ingratiates himself with her father, and manages to marry her; she

[16] The quip with the mango-fruits recurs in Prabandhacintāmaṇi (Tawney's Translation), pp. 5, 6.

does not remember that they had previously exchanged repartee. At night he recalls himself to her memory, when she says: "Yes, country bumpkins are tricked in this way by city wits." Then he replies: "Rest you fair, city wit; I vow that the country bumpkin will desert you and go far away." She then vows in her turn that a son of hers by him shall bring him back again. He puts a ring on her finger, and promptly makes off to Ujjayinī, in love with her, but wishing to make trial of her cleverness.

Then the Brahman's daughter starts off to Ujjayinī in the guise of a splendidly equipped hetæra, calling herself Sumañgalā. There she poses as the beauty of the world, a position which she is able to maintain through her father's wealth and her own charm. She is approached by many suitors, but manages to elude them. Mūladeva narrates with gleeful unction, how his own friend Çaçin was chased from pillar to post in an attempt to reach her. Finally Mūladeva himself is admitted to her presence and favor. He does not recognize her as his own wife, but lives with her in great mutual love for some time, until she forges a letter from her supposititious sovereign, and disappears as she came, returning, of course, to her home in Pāṭaliputra.

In due time she gives birth to a boy by Mūladeva. This boy, at the age of twelve, is wonderfully accomplished. In a quarrel he beats with a creeper a fisher-boy who is, of course, of low caste, and the boy throws into his teeth: "You beat me, tho nobody knows who your father is; for your mother roamed about in foreign lands, and you were born to her by some husband or other."[17] The boy then extracts from his mother the whole story, including his father's name, and finally exclaims: "Mother, I will go and bring my father back a captive; I will make your promise good!"

At this point Mūladeva's own narrative becomes too good to be shortened. "The boy set out and reached this city of Ujjayinī. And he came and saw me playing dice in the gambling-hall, making certain of my identity from the description his mother had given him, and he conquered in play all who were there, and he astonished every one there by showing such remarkable cunning, tho a mere child.

[17] Cf. Prabandhacintāmaṇi, p. 170.

Then he gave away to the needy all the money he had won at play. And at night he came and stole my bedstead from under me, letting me down gently on a heap of cotton while I remained asleep." We must remember that gambling is Mūladeva's pet vice which brings him to grief in Devendra's novel, and that, furthermore, he is "prince of thieves," author of a steya-çāstra or "thieves' bible." Stealing a bedstead from under such as he, is like stealing the white of Sherlock Holmes' eyes. Mūladeva continues: "So when I woke up, and saw myself on a heap of cotton, without a bedstead, I was at once filled with mixed feelings of shame, amusement, and astonishment. Then, O king, I went at my leisure to the market-place, and, roaming about, I saw there that boy selling the bedstead. So I went up to him and said: 'For what price will you give me this bedstead?' Then the boy said to me, 'You cannot get the bedstead for money, O crest-jewel of cunning ones; but you may get it by telling some strange and wonderful story.' When I heard that I said to him, 'Then I will tell you a marvelous tale. And, if you understand it and admit that it is really true, you may keep the bedstead; but if you say that it is not true and that you do not believe it, you will be illegitimate, and I shall get back the bedstead. Now listen! Formerly there was a famine in the kingdom of a certain king; that king himself cultivated the back of the beloved of the boar with great loads of spray from the chariot of the snakes. Enriched with the grain thus produced the king put a stop to the famine among his subjects, and gained the esteem of man.'

"When I said this the boy laughed and said: 'The chariots of the snakes are the clouds; the beloved of the boar is the earth, for she is said to have been most dear to Viṣṇu in his boar incarnation; and what is there to be astonished at in the fact that rain from the clouds made grain to spring on the earth?'"

The boy then, in his turn, poses a cosmic-mythological riddle—dear to the heart of the Hindu from the time of the theological brahmodya of the Veda—on the condition that, if Mūladeva solves it, he gets the bedstead; if not he becomes the boy's slave. Of course, Mūladeva fails; the boy takes hold of his arm, and takes him to his mother in Pāṭaliputra. Mūladeva, the unstable scape-grace, lived

there "a long time" with that wife and that son, and then returned to Ujjayinī, unable to keep steady company for ever.

Mūladeva is not merely versed in the direct arts, practices, and tricks of love; he is also celebrated in all accessories. He is a cultivated conversationalist; brilliant narrator; marvelous musician; expert in massage, perfumes, and ointments;[18] knows how to send a lady a present; in fact, man of the world and *arbiter elegantiæ*, or according to the Hindu Love-Bibles, a typical nāyaka, or "hero," who must really control no less than sixty-four accomplishments. These qualities come to the fore in Devendra's story.

In the broader sphere of tradition he, or his double Karṇīsuta, is a dhūrtapati, "master-thief," and author of a steya-çāstra. In the story of Maṇḍiya,[19] another of Devendra's stories, Mūladeva, after he has become king of Beṇṇāyaḍa, figures as a resourceful thief-catcher (à la Haroun-al-Rashid); cf. Kathāsaritsāgara 88 and 112; Vetālapañcaviṅçati 14 (Çivadāsa 13). As a corollary to his artistry in this science we may regard the statement that he was an adept in cipher. This is also one of the necessary qualifications of the great Hindu Macchiavelli, the celebrated Cāṇakya, Minister of king Candragupta, who like Richard III, was born with teeth in his mouth.[20] Cāṇakya goes by the nick-name Kāuṭilya, *i. e.*, "Crooks."[21] The recent publication of his Arthaçāstra, or "Science of Politics" is one of the important events of Indology.

Mūladeva is, furthermore, a great magician. In Devendra's story he slaps a hunch-backed female slave upon the back, and, presto, she becomes straight. Particularly he has always at his hands one of those magic pills.[22] They are familiar in Devendra's stories; in the

[18] In Weber's Catalog of the Royal Library in Berlin, vol. I, p. 306, Mūladeva is mentioned in a series of authors on personal toilet: snānīya-sugandhisamuddeçaḥ . . . mukhavāsasamuddeçaḥ . . . sarvottamasāurabhya-samuddeçaḥ, and so on.

[19] See Jacobi, "Ausgewählte Erzählungen," p. 65.

[20] Teeth hadst thou in thy head when thou wast born, to signify thou camest to bite the world. Henry VI.

[21] Cf. Daçakumāracarita 1 (end); Çukasaptati 3 (where Kuṭila is the name of a rogue).

[22] Gulikā, guḍikā, guṭikā; in Vetālapañcaviṅçati 14 (Civadāsa's version) siddhaguṭikā; in Bṛhatkathāmañjarī 9. 743, yogaguṭikā (correct); ibid., 9. 731,

story of Mūladeva our hero thus transforms himself into a dwarf. All sorts of devices for such transformations are familiar in Hindu fiction; see especially Kathākoça, pp. 103, 110, 114, 130, 135, 184; Kathāsaritsāgara 37 and 74 (cf. Tawney, II, p. 632); Prabandhacintāmaṇi, p. 106; Meyer's Translation of Daçakumāracarita, p. 83.

The dramatic, or almost tragic note in Mūladeva's character is his love for gambling. In the story digested above the boy, on arriving in Ujjayinī, finds his father duly engaged in gambling in the gambling-hall, just as the theft of the bedstead is a jibe on Mūladeva's reputation as master-thief. In Samayāmātṛkā 6.29 Mūladeva is said to be skilled in the practices of the demon Kali, meaning that he is a gambler. Devendra's story begins by telling that his father drove him from home on account of this passion of his. In the same story he, like Yudhiṣṭhira or Nala, loses his all by gambling; in consequence he is humiliated by a rival, and is driven from the side of his beloved, the hetæra Devadattā.[23]

It is a curious, yet rational trait of story tradition that an outside atmosphere of complacency or benignity surrounds the scape-grace shape of Mūladeva. The story-tellers all like him. Don Giovanni must go to perdition in the end, but, as long as he lives, he is too entertaining to be read out of stage or drawing-room. It is true that one solemn Jain text, the Jñātādhyāyana 19, cites him, or what amounts to the same, his companion Kaṇḍarīka, as a forbidding example of sensuality.[24] Yet there is no mistaking that he is beloved of the romancer. And so it has come to pass that this dissolute rogue and companion of the base, this "Schlaumeier and Erzspitzbube," as Jacobi once designated him, is done over into a real pious hero by another Jain writer, Devendra, the author of the Vṛtti to the Uttarādhyāyana. We are accustomed to an important difference in the handling of fiction by Brahmanical texts on the one hand and Buddhist and Jinist texts on the other. Brahmanical fiction is essentially secular, tho it is employed sententiously to illustrate both the

yogaghaṭikā or yogāñgulikā (both corrupt); in Sāmavidhāna-Brāhmaṇa 3. 4. 3, golikā. See above, and Jacobi, "Ausgewählte Erzählungen," p. 9, line 38; 10, line 1; 31, lines 29–33.

[23] See below, p. 641.

[24] See Leumann, WZKM. vi. 43.

utilitarian and moral aspects of life (artha, kāuṭilya, nīti, dharma). But the Buddhist and Jinist texts are religious forthright; they teach the high piety, the high moral law, the dhamma. Yet they work up the same variegated, unmoral, often immoral fiction, and that, too, always under the cloak of teaching the law (dhammakathā, dhammakahā). The texts are full of curious discrepancies between the tissue of the story which is often palpably phlogistic, so to say, if not prurient, and the sententious piety which hangs from it as loose embroidery. It comes as a shock when we read in Aṇḍabhūta-Jātaka, how a king who is the future Buddha hires a professional rascal (dhutta) to corrupt an innocent young girl by pander's tricks worthy of the doctrines of the Kuṭṭanīmata or Samayāmātṛkā, in order that he may beat his own chaplain (purohita) at gambling. The text has in mind to bring out in strongest relief the mental superiority of the Buddha, but at what cost? It is hard to shut out the impression that those good saints, those Bhikkhus and Arhats; those Sāhus and Kevalins liked a romantic, or even salacious story for its own sake; that they sat there in their vihāras and āçramas with something very like the ghost of a smirk on their faces listening to what people will always listen to, but saving their faces in the end by drawing the moral which tacks itself gratuitously to the heels of almost any naughty entertainment.

The story of Mūladeva, as told by Devendra, is a *tour-de-force* of this sort, which is hard to beat and not quite easy to understand. Mūladeva is still the gambler who gambles away the clothes off his back; the black-art practitioner; the musician; the companion of low women; the *viveur;* and the resourceful adventurer. None of these qualities, we must note, respond to the Jinistic ideal. But the story recoins many of these values; it makes him out a veritable pattern and exemplar: skilled in every accomplishment, versed in many arts, noble of mind, of grateful disposition, a heroic protector, virtuous, clever, and gifted with beauty, grace, and youth. Or, in the words of Devadattā, the hetæra, whose devotion to him is the saving motif of the story: "he is wise, of noble soul, a very ocean of kindliness, skilled in the arts, pleasant of speech, grateful, virtuous, and of discerning mind." One is surprised at hearing the jargon of the

Hindu counsel of perfection—this is about what it amounts to—on such a stage and from such mouths. The way these people declaim on, and really seem honestly to admire "virtue," fits vice-crusaders better than denizens of the lower world. Aside from this paradox the happenings of the story, event by event, are sheer romance, strangely uncongenial to an Acta Sanctorum.

The purpose of the Jinist writer is served thus: Mūladeva's fortunes sink to a very low ebb indeed, because of his passion for gambling, and the rivalry of a rich suitor for the favor of Devadattā, named Ayala. In the end he manages by dint of a frankly selfish act of piety to obtain success through the favor of the gods. He gives his own scant food, which he has just obtained by begging, to a saintly ascetic who has come to a certain village, in order to break a month's fast. In consequence thereof he obtains the kingship of Beṇṇāyaḍa. The point is, that it pays to serve holy ascetics. I must say, I like Devendra, the story-teller, better than Devendra, the theologian.

Something needs to be said about the remaining characters of this story. The heroine, Devadattā,[25] belongs to the type of the beautiful and noble hetæra, gifted with every grace of heart and mind. Howsoever difficult we may find it to adjust this conception to our ideas, the fact is that with the Hindus this is a settled conception, and a settled type in fiction. The system of the erotic books deals with various grades of hetæras; the first grade, called gaṇikā, standing for the type of noble hetæra.[26] We need not try the hopeless task of appreciating such distinctions. Taken in bulk they are in the main the product of the naive schematism of the Hindu mind. Yet there is an appreciable sediment of reality as regards the beginning and end of the classification: there are vile and noble hetæras. For an extreme example of the former class see the parallel stories, Kathāsaritsāgara 58; Kathākoça, p. 128 ff.; Kalāvilāsa (Meyer's

[25] A commentator of Subandhu's Vāsavadattā substitutes the name Nagaramaṇḍanā, stating that a hetæra of that name was captivated by Mūladeva's superior intellectual qualities. See Weber, "Indische Streifen," I., 383, note 2.

[26] See Schmidt, "Beiträge zur Indischen Erotik," pp. 278 ff., 788 ff.; Meyer, Daçakumāracarita, p. 41 ff.; Samayāmātṛkā, pp. ix ff.; Çukasaptati 45.

Samayāmātṛkā, p. L ff.) As regards the noble hetæra the classical figures of Aspasia, or Phryne, or Laïs, those "companions" of antique swell society, come easily to mind as parallels, but parallels may run on different planes. The character of the Hindu hetæra is at times really noble. Such a hetæra, Vasantatilakā, is the friend of the princess Ratnamañjarī, in Kathākoça, p. 151; another one, Kuberasenā, shows the greatest devotion to her children, in Pariçiṣṭaparvan 2. 225 ff.; a third one is remarkable for her intellect in Prabandhacintāmaṇi, p. 67.

The story of king Vikramāditya and Madanamālā, Kathāsaritsāgara 38, is a story of a hetæra's true devotion which winds up with the reflection: "Thus, king, even hetæras are occasionally of noble character, and as faithful to kings as their own wives, much more than matrons of high birth." Accordingly, Prabandhacintāmaṇi, p. 116, describes the hetæra Cāulādevī as a famous vessel of beauty and good faith, excelling even matrons of good family. But the high standing of courtezans, as well as their nobility of character, is illustrated best by Vasantasenā, the famous heroine of the "Toy-Cart." She loves the Brahman merchant Cārudatta, who has impoverished himself by liberality, and ultimately becomes his wife. In our story Devadattā rivals Vasantasenā in tone and character, and yet she is a courtezan with a villainous "Mama" to guide and browbeat her, and otherwise surrounded with all the animate and inanimate real properties of her vocation. The description of the Mama, as given in Samayāmātṛkā and Kuṭṭanīmatam, shall not blacken these pages,[27] but I may draw attention, as one of the gems of our romance, to the symbolic debate between the Mama and Devadattā which contrasts the former's sordidness with the latter's refinement.

In the legend at large Mūladeva is in the habit of training with a friend, or boon companion. Mention has been made above (p. 622) of one Kaṇḍarīa (Skt. Kaṇḍarīka), but Kaṇḍarīka belong rather to the Bambhadatta cycle of stories, as one name (the other is Varadhaṇu, or Varadhaṇuga) of the *fidus Achates* of the adventurous prince Bambhadatta.[28] In the Bṛhat-kathā books (Kathāsaritsāgara

[27] Cf. the doings of Daṅṣṭrākarālā and Dhūrtāmāyā in Çukasaptati 22 and 23.

[28] Cf. Leumann, WZKU. vi. 43.

and Bṛhatkathāmañjarī) the name of Mūladeva's companion is Çaçin. The commentator Bālakṛṣṇa, to Bāṇa's Kādambarī, 19.16 (Peterson's edition), alludes to him as çaça "Hare."[29] This Çaçin, a sort of Leporello to Mūladeva's Don Giovanni, flits across the Mūladeva legend with tantalizing elusiveness: we should like to know more of him. It is rather curious that Devendra's novelette fails to mention him. But I think that he is, after all, there by reflection. When Mūladeva is driven out of Ujjenī by the Mama's machinations, he starts without a penny to bless himself with for Beṇṇāyada, where he ultimately becomes king. On the way he comes to an extensive forest. At the sight of it he reflects that, "if he could meet some other person traveling in the same direction, so that he might at least have someone to talk to, the journey through might be pleasant enough." Opportunely there comes along a Ḍhakka-Brahman, which I take to mean a "Brahman of the Thugs."[30] In his company Mūladeva crosses the forest. There is regularly a touch of facetiousness in this road-companionship, but this time the joke is rather on Mūladeva. For three days they travel together. Mūladeva has nothing to eat, whereas the Ḍhakka has a well-provisioned knapsack. At each meal-time the Ḍhakka feasts without offering Mūladeva anything, until the time comes for parting. They exchange names and addresses, and Mūladeva, tho treated thus shabbily, expresses his gratitude for the companionship. Later on, when he has become king Vikrama, he presents the Ḍhakka with a village. The curious anecdote seems to me to reflect the companion of Mūladeva, and to serve the additional purpose of placing in strong relief the grateful disposition which the story explicitly ascribes to Mūladeva.

The Jaina story of Mūladeva in Māhārāṣṭrī Prākrit, by the Jaina chronicler Devendra,[31] gathers up the adventures and unfolds the

[29] The same authority mentions also Acala (Ayala), Mūladeva's rival, as one of his friends. Also a personage by the name of Vipula, otherwise unheard of in the story: Karṇisutaḥ Karaṭakaḥ steyaçāstrapravartakaḥ tasyākhyātāu sakhāyāu dvāu Vipula-Acalasamjñitāu Caçaç ca mantripravaraḥ.

[30] See the note below, p. 641.

[31] Edited by Jacobi, "Ausgewählte Erzählungen in Māhārāṣṭrī," pp. 56–65; elaborated, or translated by Pavolini, "Vicende del Tipo di Mūladeva,"

character of this singular personage more completely and consistently than all the rest of the data which occur scatteringly in the remaining literature. It is a legendary biography without any real historical value. There certainly existed at some time or another an author Mūladeva, the son of the woman Karṇī (or Goṇī), skilled in the *ars amatoria* and kindred topics. But this connected quasi-biography, well-knit and consistent, a rattling good story, so to speak, reveals itself on closer inspection as both legendary and unoriginal. The individual items of the story are for the most part recurrent motifs from earlier sources. Devendra's skill lies in his power to connect and to imbue with life the separate members of his story. The shifting, flitting, shadowy figure of Mūladeva shapes itself into a real person in his hands. Devadattā, in whom is embalmed the notion of the noble hetæra, becomes, whether we will or not, a personage altogether lovable. The Mama makes us forget her own baseness by the sheer force of her character and the wit of her utterances. Her sayings and doings are, perhaps, the best and most original feature of the story. Mūladeva's rival, Ayala, is well delineated. Mūladeva's mishaps, the manner in which he prepares for greatness, his dream of kingship, and his choice as king of Beṇṇāyaḍa are well told. The entire setting of the story, from the moment that Mūladeva arrives in Ujjenī and becomes acquainted with Devadattā, betrays the practised skill of a good dramatist, and reveals Devendra as more than a rival of the best Jātaka-narrators. In the following translation the parallels to the individual items are stated in the notes, without, however, going into the details of comparison. For the materials involved in these comparisons, as indeed for the data involved in this essay as a whole, I am indebted in part to the essays or translations of the scholars mentioned in the foot-note on p. 632. Jacobi's excellent edition of Devendra's stories with vocabulary has long been an Indological classic.

Giornale della Società Asiatica Italiana, IX. 175 ff.; by Charpentier, "Paccekabuddhageschichten" (Upsala, 1908), pp. 57 ff.; and by John Jacob Meyer, "Hindu Tales" (London, 1909), pp. 193 ff.

The Adventures of Mūladeva as told by Devendra.

There is a city called Ujjenī. A certain Rajput, Mūladeva by name,[32] had been cast out by his father because he was addicted to the vice of gambling,[33] and after roaming over the earth had come to this city from Pāṭaliputta. He was withal skilled in every art; versed in many sciences; of noble mind; of grateful disposition; a hero to those who sought his protection; devoted to virtue; courteous; clever; and gifted with beauty, grace, and youth. In Ujjenī he changed his appearance by virtue of a magic pill,[34] took on the shape of a dwarf, and astonished the city folk by his many stories, by his skill in music and other arts, and by the performance of sundry jugglers' tricks, so that he became a celebrity.

Now there lived at that time in Ujjenī a most elegant courtezan, Devadattā by name, proud of her beauty, charm, and intellect. Mūladeva heard that her pride was such that she took no pleasure in any ordinary mortal. He became curious, and, in order to stir her emotions, stationed himself at daybreak near her house, and began to intone a sweet-sounding melody. His voice vibrated with its many modulations; his song was exquisite in the harmony of its various sounds. Devadattā heard it and thought: "Ah, what an incomparable voice; this must be a god, not a mere man!"[35] She sent out her slave-girls to look for him, and, when they found him, they saw that Mūladeva had the shape of a dwarf, all of which they reported to Devadattā. She then dispatched a hunchbacked slave, Māhavā by name, to call him. Māhavā went up to him, and addressed him politely: "Very noble sir, my mistress Devadattā bids thee favor her with a visit to our house."

Mūladeva slily disguised his purpose, and answered her: "I have

[32] The part of the story beginning here, up to the point where Mūladeva is disgraced by Ayala, is essentially the same as the story of Lohajaṅgha, Kathāsaritsāgara 12. 78 ff.; see the notes in Tawney's Translation, vol. I., p. 574.

[33] Cf. Kathasāritsāgara 121.

[34] See above, p. 627.

[35] The theme of the lure of a beautiful voice recurs frequently (see Benfey's Pañcatantra i. 436 ff.): Meyer, "Hindu Tales," p. 263 ff.; Ardschi-Bordschi-Chan, second interpolation in 11th story (Jülg, Mongolische Märchen); Goontilleke, Orientalist, i. 277 ff.

no use for the society of courtezans; genteel men are forbidden to associate with dissolute women. As the poet says:[36]

"A courtezan is a most degraded person; she is worn out by countless gallants, is given over to drink and gluttony. She is soft of speech, but evil of mind: such a one is not regarded by gentles.

"Like the crest of a flame her nature is to devour; like intoxicating drink she bewilders the senses; like a razor she cuts the body; aye, like a thorn the courtezan is rued!

"Therefore I have no desire to go to her."

The slave-woman, however, beguiled his soul with many enticing expressions, insistently took him by the hand, and led him to the house. As he went he slapped her crooked back, and by virtue of his great art and magic skill, she was made straight. With astounded mind she brought him to the house, where Devadattā beheld him, a dwarf in shape, yet incomparably charming. In a daze she bade him be seated, and offered him betel.[37] Then Māhavā exhibited her restored figure, and told the whole story. Devadattā, still more amazed, began to converse in sweet and cultivated language: her heart was attracted to him. As says the poet:

"The conversation of clever men, pleasant in its courtliness, adroitly witty, delightful in its delicate sounds, that is sorcery—what use is there in magic roots!"[38]

It happened that a certain lute-player arrived there and sounded his lute. Devadattā was pleased, and exclaimed: "Bravo, Mister lutist, bravo, your skill is exquisite!" But Mūladeva said: "Ah, the Ujjenī-folk are passing clever; they know the difference between what is beautiful, and what is not beautiful." Devadattā asked: "Sir, what is wrong here?" Mūladeva replied: "The tube of the lute is unclean; the string full of flaws." She asked how he knew,

[36] These two stanzas are quoted in Sanskrit; Charpentier, *l. c.*, p. 59, suggests that they may be from a lost work by Mūladeva himself. See another description of the baseness of courtezans in Çukasaptati 23.

[37] For the use of betel in erotic practices see Schmidt, "Beiträge zur Indischen Erotik," Index, p. 945; for its character and chronology see Hörnle, "Uvāsagadasāo," Translation, p. 20, note; Speyer, "Studies about the Kathāsaritsāgara," p. 49.

[38] See Meyer's good note on this stanza, p. 195.

and he said, he would show her. The lute was handed him, and he drew a pebble from the tube, and a hair out of the string.[39] Then he put it in order and began to play. Devadattā and her attendants were transported. A she-elephant nearby which was always in the habit of roaring stood still rocking herself, with her ears down.[40] Devadattā and the lute-player in surprise thought: "Verily, he is Vissakammā (the Creator) in disguise!" Then she dismissed the lute-player with presents.

Dinner-time arrived and Devadattā ordered the massagist, so that they might both bathe. Mūladeva said: "Permit me to do your anointing."[41] Devadattā asked: "What! do you know this also?" and Mūladeva replied: "I do not know it perfectly, but I have stood in the presence of them that know." They brought campaka-oil; he proceeded to anoint; she was enchanted. And she thought: "What exceeding skill, what unexcelled touch: he must be some divine personage in disguise; ordinarily such excellence does not reside in a person of such shape. I must make him disclose his true shape!" She fell at his feet, and said: "Noble Sir, your unparalleled virtues of themselves mark you as a superior person. Such a one is gracious to those who appeal to him, and anxious to oblige. Show me therefore your true self, my heart longs greatly to see you!" When she kept on importuning, Mūladeva, laughing softly, removed the magic pill which had changed him, and assumed his true form. He appeared resplendent as the sun, like the God of Love bewildering all creatures by his beauty, his body abounding in

[39] Marvelous skill in detecting flaws in objects that are supposed to be perfect, Suppāraka-Jātaka, first part. Cf. the four wonderful house-servants of King Jitāri, Weber, "Handschriften-Verzeichniss," Vol. II., p. 1093, bottom; or the skill tricks in Pariçiṣṭaparvan 8. 170 ff.; Prabandhacintāmaṇi, p. 45.

[40] In Kathākoça, p. 65 ff., occurs a tourney of lute-players for the hand of princess Gandharvadattā: the music of the first quiets a mad elephant; that of the second makes a tree burst into blossom; that of the third attracts a distant deer; that of the fourth makes an elephant give up a half devoured sweet; and, finally, a fifth soothes the entire assembly to sleep. In Prabandhacintāmaṇi, p. 122, the musician Solāka sings so that a dry branch bursts forth into buds. In Kathāsaritsāgara 11 King Udayana subdues evermore with his lute wild elephants, and taming them brings them home.

[41] One of the sixty-four accomplishments (kalā) of the typical man of the world (nāyaka). See Schmidt, "Beiträge," p. 143.

fresh youth and grace. The hair on Devadattā's body stood erect with joy;[42] she again fell at his feet, and said, "You have shown me great favor!"

Then she anointed him with her own hands, and they both bathed and feasted in great state. She had him dressed in a robe fit for a god, and they passed the time in genteel conversation. Finally she said: "Noble Sir, excepting yourself, my heart has never inclined to any man. As has been truly said:

"'Whom may not one see with one's eyes, and with whom may not one hold conversation? Rare, however, is that quality in man which arouses joy in the heart.'[43]

"Therefore, to please me, you must come to this house quite constantly."

Mūladeva said: "O thou, that art devoted to virtue, an attachment to such as me, stranger that I am and poor, is not proper, nor is it likely to endure. As a rule attachments spring from self-interest alone. As the poets say:[44]

"'Birds abandon a tree whose fruit is gone; cranes a dried-up lake; bees a withered flower; and game a burnt forest.'

"'Courtezans abandon an impoverished man; servants a fallen king. Every person loves from self-interest; no one regards any other attachment.'"

Devadattā replied: "Own country or strange country are of no consequence to noble men.[45] The poet says:

"'The moon, though separated from the ocean, dwells on the head of Hara: wheresoever virtuous meṇ go there they are carried on the head.[46] Likewise, wealth is of no consequence; noble men do

[42] Horripilation in Hindu stories is produced by joy as well as by fear; *e. g.*, Kathāsaritsāgara 10, 14, 124.

[43] According to Pavolini, GSAI. ix. 179, note, this stanza recurs in the Gāthākoça of Muṇicandrasûri.

[44] The following two stanzas are again in Sanskrit, quoted from an unknown author.

[45] This quasi proverbial statement is nullified by frequent expressions of love for home and country in Sanskrit literature; see Meyer's "Translation of Daçakumāracarita," p. 222, note.

[46] Hara (Çiva) wears the moon, whose original home is the ocean, as a diadem on his head: see Mṛcchakaṭikā (Stenzler's edition), p. 64, l. 10; Samayāmātṛkā 4. 26, 27, 29.

not attach much value to it; to virtue alone is their inclination.' Anent this it is said:

"'Speech is valued at a thousand; the rewards of love at a hundred thousand. But the devotion of a noble man exceeds a krore.'

"Therefore, by all means yield to my wishes." Then he consented, and there sprang up between them a union of surpassing love.

It came to pass that Devadattā danced before the king, while Mūladeva beat the drum. The king was delighted, granted her a boon, which she laid up in store.[47] But Mūladeva was so passionately addicted to gambling, that he did not keep even the clothes on his back. Devadattā, sweetly spoken, administered a friendly rebuke: "Dearly beloved, the passion of gambling in thee, that art the resort of all virtues, is a blemish, like the figure of the gazelle on the full-moon.[48] Gambling, as the poet says, is the foundation of every sin:[49]

"Gambling disgraces the family; is the enemy of truth; brings shame and grief upon parents and teacher. It destroys piety, and wastes property. It precludes liberality to others and own enjoyment; it steals from child and wife, from father and mother. O beloved do not adhere to this vice which makes forget God and teacher, and right and wrong; which ruins the body and leads to hell!

"Aye, by all means desist from this vice!" But Mūladeva could not control his exceeding passion.

Now there was a rich son of a merchant, Ayala by name, who had a host of friends, and was deeply smitten with Devadattā. He gave her whatever she asked; sent her clothes, jewels, and other presents. He bore Mūladeva a grudge, and sought out his vulnerable points. Mūladeva regarded Ayala with suspicion, and did not come to the house, unless there was some special occasion. Now Devadattā's "Mama"[50] said to her: "My child, drop Mūladeva! You

[47] This practice is referred to quite frequently: Kathākoça, p. 48; Prabandhacintāmaṇi, p. 77; Jātakas, Vol. I, p. 24.

[48] The Hindus fancy either a gazelle or a hare in the moon.

[49] Cf. the reflections on gambling in the gamblers' stories, Kathāsaritsāgara 121.

[50] This "Mama" is sometimes the real mother of the hetæra, but, generally speaking, rather a hired manager. See Dhanaṁjaya's Daçarūpa 2.

have no use for this penniless gallant, whereas Ayala is a stupendous giver who keeps on sending much wealth; attach yourself to him with all your soul! Two swords do not go into one scabbard, and one does not polish a non-precious stone.[51] Therefore drop this gambler!" Devadattā answered her: "I am not, my mother, bent upon money alone; to noble qualities rather is my inclination." Her mother asked of what sort were the noble qualities of that gambler, and Devadattā retorted: "Mama, he is altogether made up of virtues:

"He is wise, of noble soul, a very ocean of kindliness; skilled in the arts, pleasant of speech, grateful, devoted to virtue, and of discerning mind; therefore I shall not give him up!"

Then the mother started to convert her by means of sundry symbols: when Devadattā asked for red lac she gave it her dry; when she asked for sugar-cane she gave it her squeezed; when she asked for flowers she gave her mere stems.[52] And when pressed to explain, she said: "Of such sort is that most beloved of thine, and yet you will not give him up." But Devadattā thought that the mother was foolish in offering such illustrations.

(By way of counter-illustration) Devadattā then said to her mother: "Mama, ask Ayala for sugar-cane!" She spoke to him, whereupon he sent a cart-load. Devadattā burst out: "What, am I a she-elephant, to have sent me such a load of cane with leaves and branches?" The mother pointed out that he must surely be liberal to have sent in this wise. (Of course) Ayala had figured that Devadattā would share with others. Next day Devadattā said to Māhavī: "My dear, tell Mūladeva, Devadattā has a craving for sugar, therefore send her some!" She went and told him. Now

20; Samayāmātṛkā 1. 40 ff.; and especially 4. 9 ff. The Mama's greed for money comes out, ibid., 4. 80; her hostility to poor lovers of her charge, ibid., 5. 80 ff.

[51] The rendering of the second of these proverbs is not quite certain.

[52] These three symbols state technically how a hetæra should estimate her lover in dollars and cents. They appear to be borrowed directly from Samayāmātṛkā 5. 78: "After she (the hetæra) has sucked him (the lover) dry, and his serviceableness is at an end, she should throw him off like a squeezed stick of sugar-cane; for a withered flower disfigures the place where it has been put, and is removed from the braid of hair."

Mūladeva took two sticks of cane, cut them into blocks two inches in length, sprinkled them with a mixture of four spices,[53] made them fragrant a bit with camphor, and split them slightly at both ends. Then he took some fresh jessamine, covered the cane with it, packed it and sent it off.[54] Māhavī went and delivered it; then Devadattā showed it to the mother, saying: "Regard, Mama, the difference between men: this is why I am taken with these his qualities."

The mother concluded that Devadattā was hopelessly infatuated; that she would not of her own accord let go of Mūladeva; and that, therefore, she herself must find a way by which that gallant might be driven out: then all would be well. So, after reflection, she said to Ayala: "Pretend to her that you are going to another town. Then, when Mūladeva has come, do you arrive with a retinue and shame him in such a way that he will leave the place in disgrace. Then you two will be united. I shall furnish you the needed information." He agreed, and on the next day did just as he had been told. He went off, pretending that he was going to another town. Mūladeva came; Ayala was informed by the mother, and arrived with a large retinue.

Devadattā saw Ayala coming, and said to Mūladeva: "Such and such is the situation; mother has accepted money sent by him. Do you therefore for a while hide under the couch." He did so, but Ayala spied him, seated himself upon the couch, and told Devadattā to get ready all the belongings of a bath. Devadattā agreed and told him to get up and put on a robe, in order to be anointed.[55] Then Ayala said: "I saw to-day in a dream, that I would be dressed, anointed, and bathed here upon this couch; make then my dream come true." Devadattā asked whether he wished to spoil all the valuable belongings, such as coverlets and pillows, but he replied that he would give her others, more sumptuous. The Mama agreed with this; Ayala was anointed, massaged, and washed with warm bath-

[53] Cāturjāta; cf. Schmidt; "Beiträge zur Indischen Erotik," p. 850.

[54] Cf. perhaps the games called ikṣubhañjikā "breaking of sugar-cane," and navekṣubhakṣikā "feasting on fresh sugar-cane," mentioned in Schmidt, "Beiträge zur Indischen Erotik," p. 196. They belong to the accomplishments of the nāyaka, or "elegant."

[55] Cf. the dripping vesture after a bath of the heroine in Karpūramañjarī i. 27; and see Meyer's note on this passage, p. 203.

ing water right there on the couch, so that Mūladeva, who lay underneath, was drenched with it. Then Ayala's men entered, armed, and the mother gave the signal. Ayala seized Mūladeva by the hair, and said to him: "Ho there! see now if you find any one to protect you!" Mūladeva looked about him, and perceived that he was surrounded by men with sharp swords in their hands. Then he reflected: "I cannot get away from them, but I must live to retaliate for their enmity. Now I am unarmed, so this is not the time for heroic deeds." Then he said to Ayala: "Do what you please!"

Ayala observed that Mūladeva by his very carriage showed himself to be a person of distinction, and reflected that great men in the course of the revolving cycle of existences easily get into misfortune. As the poet says:

"Who in this world is always lucky, who can rely upon Fortune's favors? Who does not on occasion take a fall, aye, who is not crushed by fate?"

Then he said to Mūladeva: "Tho you have come to such a pass, do you now go free, and, if ever, by the might of fate, I should come to grief, treat me just as I have treated you!"

Then Mūladeva went from the city disspirited and sad, brooding: "See how I have been tricked by this man." He first bathed in a clear pond, and then decided to travel to a distant land, there to devise some scheme of retaliation.[56] He set out toward Beṇṇāyaḍa. After passing many villages and towns he came to the edge of a forest twelve leagues in length. It occurred to him that if he could meet some other person traveling in the same direction, so that he might at least have some one to talk to, then the journey through might be quite pleasant. After a while there approached a Ḍhakka-Brahman[57] of distinguished appearance, equipped with a sack of

[56] A sort of "Live to fight another day." See the proverbial statement to that effect, Pariçiṣṭaparvan 8. 256.

[57] The words ḍhakka, ṭhakka, ṭakka, ṭāka, Mahratti ṭhaka, are Hindu terms for a despised people, tribe, caste, or guild; see Kern, "Indische Studien," XIV. 396; Meyer, to the present passage, p. 205, note. According to Pischel, "Grammatik der Prākrit-Sprachen," § 25, a dialect called Dhakkī is spoken by gamblers in the second act of the Mṛcchakaṭikā. Sanskrit sthaga, "cunning, sly, fraudulent, dishonest," reported by the lexicographers, is probably the same word; cf. Sthagikā, the name of a thieving courtezan,

provisions. Mūladeva asked: "Reverend Sir, have you far to go?" He replied: "There is beyond the forest a place called Vīranihāṇa; there is where I am going. And where may you be bound for?" Mūladeva said that he was going to Beṇṇāyaḍa, and the Doctor then proposed that they should travel together. The two of them started, and, as they marched along, they saw at noon-time a clear pool. The Dhakka proposed that they should rest a while, whereupon they went to the water and washed their hands and feet. Mūladeva sat down in

Çukasaptati 7. The words most frequently imply stinginess. Mahratti ṭhaka, according to Yule, "Dictionary of Anglo-Indian Terms," is the name in that language of the notorious guild of the Thugs (see under that word), and it seems to me likely that we have in all these words the precursors in Hindu literature of the Thugs, or Phansigars, even though stinginess and roguery, rather than murderousness, are their characteristics in the literary documents referred to. According to Hörnle, Uvāsagadasāo," Appendix ii, note 8, Pāli cora-ghātaka, German "Raubmörder," is the equivalent of modern ṭhag. I add here the curiously parallel Ṭakka-anecdote from Kathāsaritsāgara 65. 140 ff.: "There lived somewhere a rich but foolish Ṭakka who was a miser. He and his wife were always eating barley-grits without salt, and he never learned the taste of any other food. Once the Creator moved him to say to his wife: 'I have conceived a desire for a milk-pudding; cook me one today.' His wife agreed, and proceeded to cook the pudding, while the Ṭakka remained indoors, concealed in bed, for fear some one should see him, and drop in on him as a guest. In the meantime a friend of his, a Ṭakka who was fond of mischief, came there, and asked his wife where her husband was. And he, lying on the bed, said to her: 'Sit down here, and remain weeping and clinging to my feet, and say to my friend: "My husband is dead." When he is gone we will comfortably consume this pudding.' After he had told her this she began to cry, and the friend came in and asked her what was the matter. She said to him: 'Look my husband is dead.' But he reflected: 'I saw her a moment ago happy enough, cooking a pudding; how comes it that her husband is now dead, tho he has had no illness? No doubt the two have arranged this trick, because they saw that I had come as a guest. So I will not go.' Thereupon the mischievous fellow sat down and began crying out, 'Alas, my friend! Alas, my friend!' Then his relations came in and prepared to take that silly Ṭakka to the burning-place, for he still continued to counterfeit death. But his wife came to him and whispered in his ear: 'Jump up, before these relation take you off to the pyre and burn you.' The foolish man answered his wife in a whisper: 'No! that will never do, for this cunning Ṭakka wishes to eat my pudding." The story goes on to tell that the stingy Ṭakka actually allowed himself to be burned, sacrificing his life in order to save his pudding. The story does not, as far as I can see, occur in the two sister-texts of the Kathāsaritsāgara, namely, Bṛhatkathāmañjarī and Bṛhatkathāçlokasaṁgraha.

the shade of a tree on the bank. The Ḍhakka loosened his provision-sack, put grits into a dish, moistened them with water, and fell to eating. Mūladeva thought: "This is just what you might expect from the Brahman gang, to be given over to feeding;[58] doubtless he will offer me some later on." But the Doctor, after having eaten, tied up his knapsack, and proceeded on his way. Mūladeva followed, hoping that he would give him something in the evening. Yet in the evening he ate in exactly the same way, and did not give him anything. Mūladeva proceeded, hoping that he would give him something in the morning. Night overtook them as they traveled; they stepped from the road, and slept under a banyan-tree. At daybreak they set out again; at noon they halted after the same fashion, but the Ḍhakka ate just as before, giving him nothing. On the third day Mūladeva thought that, now that the forest was almost crossed, he would surely on this day give him something. Yet even then he did not give him anything. They crossed the forest, and their roads parted. The Doctor said: "Sir, this is your road, and this is mine; depart you therefore by this." Mūladeva said: "Reverend Doctor, I have traveled with your assistance. My name is Mūladeva: if my affairs should ever prosper, then you must visit me in Beṇṇāyaḍa. What now might your name be?" The Ḍhakka said: "Saddhaḍa, but people also know me by the nick-name Nigghiṇasamma."[59] The Doctor then started for his village; Mūladeva proceeded to Beṇṇāyaḍa.

After a while he perceived a house which he entered for alms. After that he tramped through the entire village, obtaining some lentils, but nothing else. Then he started toward a pool. There shortly he perceived a mighty ascetic of great majesty, his body lean from abstinence, who was entering (the village) to break a month's fast. When Mūladeva saw him the hair on his body stood erect with joy, as he thought, "Oh, I am in luck, my fortune is made, since this

[58] A Brahman without greed is hard to find, according to Harṣacarita 6 (Bombay edition, 1897, p. 181); cf. Weber, "Indische Studien," X., 61, 62.

[59] Saddhaḍa seems to mean, ironically, something like "Pious Giver"; Nigghiṇasamma, something like "Devotee of Pitilessness."

mighty ascetic has at this juncture come within the path of my sight. For I shall certainly come into fortune:

"As the wish-tree in the Marutthalī-desert, as a shower of gold in a poor man's house, as a royal elephant in the house of a Pariah, thus here is this great-souled saint.

"Purified by insight and knowledge; intent upon the five great vows; wise; endowed with patience, gentleness, and rectitude; intent upon salvation; devoted to study, meditation, and self-mortification; pure in thought; engrossed with the five-fold samiti-virtues, and the three-fold gupti-restraints; without wordly goods; free from the attachments of house-holders—this noble person is a Sāhu (Saint).

"Such a person is a fruitful field, irrigated by the water of holy thought: wealth deposited in it as grain yields endless crops both here and in the other world.

"I must not therefore hesitate: I shall offer him these lentils. Since the village is stingy, this noble Sāhu, after having visited some houses, will come back here. But I shall make two or three trips, so as to get more; there is also another village nearby. Then I shall give him all I have gathered."

Thereupon, with reverent gestures, he offered his lentils to the Saint. The Sāhu, observing the perfection of his obeisance, understanding the pure-mindedness of this gift of his possessions, said: "O thou who art devoted to piety, let me take a little," and held out his bowl. Mūladeva's zeal increased as he gave, and the Sāhu chanted in metre (the following half of a stanza): "Verily, fortunate are the men whose lentils serve for the Sāhu's break of fast!" Then a divinity in heaven, devoted to the Saint, pleased with Mūladeva's piety, called out: "O son Mūladeva, thou hast done well! Therefore, in the second half of this stanza (recited by the Saint), ask what thou wishest: I shall grant all!" Mūladeva chanted: "The courtezan Devadattā, a thousand elephants, and a kingdom!" The divinity responded: "My son, live without care. Very shortly thou shalst obtain all this by the might of the sage's feet."[60] Mūladeva said: "O blessed divinity, thus be it!" Then he bade farewell and

[60] In Prabandhacintāmaṇi (Tawney's translation), p. 15, King Çālavāhana also owes his exalted station to the favor of an ascetic, to whom he, a poor carrier of wood, had given his barley-meal in order that he might break a month's fast.

returned (to the village). The Saint went to a grove. Mūladeva begged alms for the last time, ate and started for Beṇṇāyaḍa, where he arrived in due course.

By night he slept outside in the travelers' hospice, and in the last watch had a dream: The moon with full disc, her brilliance undimmed, entered into his body. Another tramp had the very same dream which he told to the rest of the tramps. One of them said: "You will to-day get a tremendously big cake full of ghee and sugar!" But Mūladeva did not tell his dream, thinking that they knew not its true meaning. The tramp started out for alms, did get from a house-wife such a cake as had been described, and joyously told the other tramps. Mūladeva went to some garden, where he made friends with a wreath-maker by helping him gather flowers. The gardener gave him some flowers and fruits. These he took, and, having adorned himself, went to the house of an interpreter of dreams. He paid his respects, and inquired about his prosperity and health. The teacher in turn addressed him politely, and inquired after his concerns. Mūladeva, with folded hands, narrated his dream, whereupon the teacher exclaimed joyously: "I shall interpret your dream in an auspicious hour; in the meanwhile now be my guest." Mūladeva accepted, bathed, and feasted sumptuously. After dinner the teacher said: "I have here a lovely daughter; out of regard for me do you marry her." Mūladeva said: "Father, would you make one whose family and character you do not know your son-in-law?" The teacher replied. "My son, behavior of itself betrays a man's family, even when he has not made mention of it." The poet says:[61]

"Behavior declares one's family, speech one's country; agitation betrays love; and personal appearance the food one subsists on."

Moreover:

"Is it necessary to impart smell to the lotus, or sweet to sugar; or to teach sport to noble elephants, or refinement to them that have sprung from a good family"?[62] And again:

[61] This stanza in Sanskrit.

[62] See Agaḍadatta, stanza 75 (Jacobi, "Ausgewählte Erzählungen," p. 72): "Who paints the peacock, or imparts their gait to the royal swans? Who bestows fragrance upon the lotus, and good manners upon them that are sprung from noble families?"

"If virtue be present, what matters family? The virtuous have no need of family; but a yet more grievous stain on the vicious is the very stainlessness of their family."

By such and the like saws he was induced to consent and marry her in an auspicious hour. Then he was told the purport of the dream, namely, that he should be king within seven days.[63] When he heard that he was rejoiced, and stayed there happily. On the fifth day he went outside the city and sat down in the shade of a campaka-tree.

At that time the king of the city died without leaving a son. Then the five royal emblems (magic electors of a king) were consecrated.[64] After roaming about within the city they went outside, and came upon Mūladeva. He was discovered sitting in shade that did not shift.[65] On beholding him the elephant roared; the steed neighed; the water-pitcher sprinkled; the chowries fanned; and the sun-shade[66] stood over Mūladeva. Thereupon the people shouted "Hail, Hail." The elephant lifted him upon his back; he was conducted into the

[63] In Pariçiṣṭaparvan 8. 231, a pregnant woman desires to drink the moon: it is a sign that her son will become king. The sight of the moon in a dream secures to Madanarehā an imperial son, in the story of Nami, Jacobi's "Ausgewählte Erzählungen," p. 41, l. 23 ff.; Kathākoça, p. 19. There are many other dreams and signs of future royalty: In Pariçiṣṭaparvan 6. 232, the son of a courtezan by a barber dreams that Pāṭaliputra is surrounded by his entrails, whereupon he becomes king of that city. In Jagaddeva's Svapnacintāmaṇi, 1. 62, we have: "He who surrounds in his dream a city or village with his entrails as a magic instrument, becomes prince in the city, ruler of a province in the village." (Half a dozen parallel verses from other texts are quoted by von Negelein, the editor of this last text.) To be born with teeth is a sign of future kingship, Pariçiṣṭaparvan 8. 196. In Prabandhacintāmaṇi, p. 80, a three-year old prince seats himself upon the throne, and is immediately crowned king. In the same text, p. 117, a king washes the feet of a hermit, and recognizes by the upward lines on them and other signs, that the hermit is worthy of a throne.

[64] On this curious, widely prevalent magic practice see now Edgerton's paper, JAOS. xxxiii. 158 ff. The list of these five magic electors follows three lines below.

[65] This is a sign of the temporal or spiritual superiority of the person sitting in the shade. Meyer, p. 212, cites several instances from Hindu literature and elsewhere, to which add Prabandhacintāmaṇi, p. 16; Kathākoça, p. 97.

[66] puṇḍarīkaṁ sitam chattram: Kṣemendra's Lokaprakāça, i. 15 ("Indische Studien," XVIII. 327).

city, and consecrated king by ministers and vassals. The divinity then appeared on the firmament of the heavens, and proclaimed: "Behold, behold, this is the puissant king Vikkama, expert in all arts; his body is permeated with divinity! Therefore, him that does not do his bidding I shall not spare." Then the entire retinue of vassals, ministers, chaplains, and others became submissive to his commands. Mūladeva lived in the enjoyment of refined pleasures of the senses. Shortly he entered into relations with Viyāradhavala, the king of Ujjenī, and they became united in close mutual friendship.

While this was going on Devadattā, after she had witnessed Mūladeva's humiliation, became exceedingly wroth against Ayala. She upbraided him: "See here, I am a courtezan, and not your wedded wife,[67] and yet you behave thus in my house: now you need not trouble yourself about me any further!" Then she went before the king, fell at his feet, and said: "Grant me the favor of that gift (which I have reserved for myself)!"[68] The king said: "Speak out, the favor is already thine; what more have you to say?" Devadattā said: "Your Majesty, I desire that no man other than Mūladeva be bidden to me, and that Ayala be forbidden to come to my house." The king said: "It shall be as you please, but tell me now, what is this affair of yours?" Then Māhavī stated the case. The king became incensed against Ayala, and said, "How now, in this my city are these two jewels, and even these this fellow does maltreat!" He had him brought up and beaten; then he said to him: "Sirrah, are you king here, that you demean yourself thus? Therefore do you now seek protection, else I shall hold your life forfeit!" Devadattā said: "My lord, what purpose is served by killing him, dog as he is in the main:[69] let him go!" The king said: "Sirrah, I am going now to release you on the word of this noble woman, but

[67] See the story, Kathākoça, p. 187, of the leper husband, as illustrating by an extreme example the devotion of a wife. In Daçakumāracarita 6 (Mitragupta's third story) we read: "Husbands are the only divinities of wives, especially of wives of good family." In Kathāsaritsāgara 13, end: "Thus, O queen, women of good family, ever worship their husbands with chaste and resolute behavior."

[68] See above, p. 638.

[69] Or, "dog-foot," as he is. In Kathāsaritsāgara 13 a dog-foot is branded on the forehead as a sign of disgrace.

you shall obtain full pardon only when you have produced Mūladeva himself." Ayala fell at his feet and went out of the palace. He began to search in every direction, but even so he did not find him. Then on the full-moon of this very month[70] he loaded ships with wares and started for Persia.

In the meantime Mūladeva sent a letter and presents to Devadattā and to king Viyāradhavala. To the king he wrote: "I am greatly attached to this Devadattā; therefore, if it so pleases her, and if it is agreeable to you, kindly send her to me." The king said to his royal wardens: "I say, why has king Vikkama sent such a letter; is there any difference between him and me? Even this my entire kingdom belongs to him, how much more Devadattā: let her, however, state her own wishes!" Devadattā was called; the matter was explained to her, and she was permitted, if she so liked, to go to him. She said: "It is very gracious of you to permit me my heart's desire." Then the king honored her with presents of great value, and she was dispatched to Mūladeva who received her in greatest state. They ruled the kingdom in common, and Mūladeva lived with her, enjoying his love, but even more engrossed with building Jina temples and images, and doing honor to the Saints.

Now Ayala, who, in the course of his tour through Persia, had amassed great wealth and choice wares, arrived at Beṇṇāyaḍa, camping without the city. He asked the people the name of the king there, and was told, king Vikkama. Then he filled a dish with coined and uncoined gold and pearls, and went on a visit to the king. The king had a seat offered him; as soon as he was seated he recognized Ayala, but Ayala did not recognize the king. The king asked: "Whence has the merchant come?" And Ayala said, from Persia. On being honored by the king Ayala proposed: "Your majesty, send some inspector to appraise my wares." Whereupon the king said that he would go in person. The king went with a revenue officer,[71] and was shown the wares on the ships, consisting of mother-of-pearl, betel, sandal-wood, aloes, madder, and so on. In the

[70] tīe ceva ūṇimāe. Thus Jacobi's uncertain conjecture; Meyer, p. 215, note, "one account of this very deficiency." He does not state his authority.

[71] pañcaulą = Skt. pañcakula: see Prabandhacintāmaṇi, pp, 18, note, and 84, and especially p. 208.

presence of the appraiser the king asked: "Look here, Mr. Merchant, is this the extent of your property?" Ayala answered: "Your majesty, it amounts to just so much." The king then ordered: "Make the merchant give half, but weigh in my presence!" The goods were weighed in bulk. By noticing their (unexpected) weight, by pushing against them with the feet, and by poking into them with a spike, valuables were found hidden within the madder[72] and the other bales. The king had the bales ripped open; a careful search revealed just where was the gold and the silver, and where the many other precious wares, such as crystals, pearls, and corals. The king, in anger, ordered his attendants: "Zounds, chain this convicted thief!" They chained Ayala, his heart beating. The king committed him to the hands of the guards, and returned to the palace.

The chief of the guards led him into the king's presence. And when the king saw him securely bound, he ordered his immediate release. Then he asked Ayala: "Do you know me?" Ayala said: "Who should not know the great princes that are famed over the whole earth?" The king said: "A truce to your flattery; say straightforth whether you know me!" Then Ayala said: "Your Majesty, I do not know you at all." Thereupon the king had Devadattā called; she appeared like a lovely Apsaras, wearing jewels on all her limbs. Ayala recognized her, and was mightily ashamed in his soul. And she said: "Behold this is that Mūladeva to whom you said at that time: 'Show thou courtesy to me also, if ever, by the might of fate, I should come to grief!' There lies your chance: now that you have gotten into danger to property and life, you are freed by the king who is kind to the humble and afflicted!" Upon hearing this he said, abashed in his soul: "Your mercy is great!" He fell at the feet of the king and of Devadattā. Then he addressed himself to the king: "I did at that time obscure Your Majesty who makes all people happy, who is adorned with every accomplishment,

[72] A curious parallel to this touch in the story occurs in Prabandhacintāmaṇi, p. 105. A young merchant "bought some sacks of madder, and, when he came to sell them, he saw some spoons of gold that had been hidden in them by merchants for fear of thieves." This text is acquainted with the Uttarādhyāyana literature in general; see p. 98.

just as Rāhu[73] obscures the ful-moon, spotless by nature: may Your Majesty pardon me that! Moreover, the king of Ujjenī, angry because I have abused you, does not allow me to enter that city." The king said: "You are already pardoned by the mercy of the queen." Ayala with great devotion again fell at their feet. Devadattā had him bathed and dressed in a robe of price, and the king remitted his duties. He was sent to Ujjenī, and Viyāradhavala, at the request of Mūladeva, pardoned him.

Nigghiṇasamma, too, having heard that Mūladeva had entered upon his kingdom, came to Beṇṇāyaḍa, and obtained an audience. The king, in a spirit of piety, presented him with the village he came from. He bowed in gratitude for the great favor and returned to the village.

At this time the tramp heard that Mūladeva had seen the same dream as himself, but that he had become king in consequence of his ardent desire. Now he thought: "I shall go where there is milk to be gotten. That I shall drink and sleep until I shall again see that dream."—As to whether he shall see it no man reporteth.

[73] The demon of eclipse.

JOHNS HOPKINS UNIVERSITY,
BALTIMORE.

OBITUARY NOTICES
OF MEMBERS DECEASED.

WILLIAM WATSON GOODWIN.

(*Read January 3, 1913.*)

William Watson Goodwin, a member of the American Philosophical Society since 1895, was born May 9, 1831, at Concord, Mass., and died June 15, 1912, at Cambridge. For fifty-six years he stood in some official connection with Harvard College. A graduate of the class of 1851, he was tutor in Greek and Latin from 1856 to 1857, tutor in Greek from 1857 to 1860, from 1860 to 1901 Eliot professor of Greek literature, from 1901 to 1912 professor emeritus, and from 1903 to 1909 overseer of the university. Even after his resignation of the Eliot professorship in 1901, his zeal did not permit him to remain inactive, and for seven years his colleagues gladly accepted his offer to continue his course on Plato and Aristotle.

In the history of education in America few men have exceeded Goodwin's period of service; and few have conferred greater distinction on American scholarship. His life is no exception to the rule that the annals of a scholar's career are short and simple. His many years were spent in unremitting and unobtrusive labor for the welfare of Harvard in a period fruitful in far-reaching changes, a period that witnessed at one end the decline of the old type of American college, and at the other the growth of the American university. He was clear-sighted in his judgment and temperate in his reasoning alike when he advocated, or when he opposed, the policies that shaped the conduct of Harvard University to its present estate.

But it is as an Hellenist that his name will live, for directly and indirectly as an interpreter of the literature and language of ancient Greece, he had a large influence on the temper and conscience of classical scholarship in the United States.

In the middle of the last century our native classical scholarship had scarcely awakened to the possibility of the independence born of original research. A leisurely interest in the classics as the humanities, a somewhat torpid belief in their efficiency as a discipline for all

mental dispositions, which was tempered but rarely by incursions into the larger meanings of Hellenic literature, sufficed with but rare exceptions for the generation under which Goodwin grew to manhood. In the year when, at the age of twenty-nine, he succeeded Felton in the Eliot professorship, Goodwin gave evidence with a certain brilliant audacity that he severed himself from the past. The year 1860 may well be taken as the mark of the appearance of a new spirit in our classical scholarship. In that year Hadley at Yale published his "Greek Grammar" based on the work of Georg Curtius; at Harvard, Goodwin brought out the book with which his name will be longest associated—the "Syntax of the Moods and Tenses of the Greek Verb."

I cannot discover that Goodwin had occupied himself especially with the problems of systematic Greek grammar in any of its aspects during his residence at the universities of Göttingen, Bonn, and Berlin; but the "Moods and Tenses" is itself a witness to the quickening spirit exercised by European masters upon the American philologists who, about the middle of the last century, began to cross the ocean in search of the inspiration they could not find at home. Yet the work, alike in its first form and when rewritten and greatly enlarged thirty years afterwards, owes relatively little to European research for its essential distinction. Not that Goodwin was not indebted, as he himself gladly acknowledged, to the labors of the great Danish scholar Madvig, or that some of his positions had not already been occupied by German syntacticians. But at the very outset of his career he had learned to think for himself—"Librum aperi, ut discas quid alii cogitaverint; librum claude, ut ipse cogites." It was due to his native and trained sense and knowledge of language as the instrument of the most delicate and refined expression that he was enabled to safeguard the subject of the modal and temporal relations of the Greek verb from the twofold danger that menaced it at the time. On the one hand, metaphysical subtlety exercised a malign influence in disturbing a clear understanding of the facts and their interpretation; on the other hand, comparative grammar, a science at that time in its infancy, by the very width of its horizon and the insecurity of its basis, threatened to carry back to the primi-

tive home of the Aryans many of the problems that pertained in the first instance to the history of the Greek language on Greek soil.

It was Goodwin's clarity of judgment—with characteristic modesty he called it "common sense"—that saw the truth when the Germans had generally failed to release themselves from the intricacies of philosophical abstractions; and with equal sagacity and discernment he refused to trust himself upon the shifting sands of comparative syntax. The metaphysical syntax that held sway when Goodwin began his career is a thing of the past; but historical syntax, both in the wider area of the Indo-European languages and on Greek territory, has immeasurably increased its influence as it has steadily built upon securer foundations.

The wonder is that after thirty years the large increments of science should have found themselves easily at home and should have worked no disturbance to the principles laid down in a book, of which its author, in his revision of 1890, said that it had appeared "in the enthusiasm of youth as an ephemeral production.". The truth is that the "Moods and Tenses" of 1890 is at bottom the "Moods and Tenses" of 1860; for, though there was much to add to a work designed to fill a larger compass, there was astonishingly little to curtail, to modify in important particulars, or to reject outright. I know of no book of like complexion which possesses the quality of prescience in equal degree. The "Moods and Tenses" displays the working of an independent and resourceful thinker, who with steadied purpose aimed at presenting the essential facts, freed from the entanglements of specious and shifting theories. To its judicious presentation of these facts, to its lucidity and precision of statement, perhaps even to its very refusal to enter at all points and at all hazards upon the treacherous ground of absolute definition, the book owes its fame as a standard work, still indispensable, despite the subsequent mass of treatises, both large and small, that traverse the whole or some part of the same field. And it has had a wider and more salutary influence than any American or English book in its province for more than half a century.

Apart from its virtues of lucidity and orderliness, there are certain special features of the "Moods and Tenses" that have com-

manded most attention: the distinction between the time of an action and the character of an action, the distinction between absolute and relative time, the division of conditional sentences (and in particular the treatment of *shall* and *will* and *should* and *would* conditions, which Goodwin discussed at some length in the *Transactions of the American Philological Association*, Vol. 7 (1876), and in the *Journal of Philology*, Vol. 8 (1879)), the relation of the optative to the subjunctive and other moods, and the origin of the construction of οὐ μή with the subjunctive and the future indicative.

The author of the "Moods and Tenses," the *doctor irrefragabilis* of Greek syntax, would have been the last to claim that he had, with Browning's grammarian, settled all of the "ὅτι's business." He had not been, like Tom Steady in "The Idler," "a vehement assertor of uncontroverted truths; and by keeping himself out of the reach of contradiction, had acquired all the confidence which the consciousness of irresistible abilities could have given." There is much in Greek syntax that is debatable territory; but whenever Goodwin entered that territory—though he was not a statistician, as the earlier great scholars were not—his prevailing soundness of judgment and his range of illustration afford the controversialist only rarely the luxury of holding a different opinion.

Goodwin's "Greek Grammar" appeared ten years after the "Moods and Tenses," and inherited as by right the distinction and the distinctive features of the earlier work. The "Moods and Tenses" appealed to the advanced student and the teacher; the "Grammar" brought before the neophyte the facts of the language in exact and clear form; and showed that its author possessed the rare (and often underestimated) faculty of making a good elementary book. Only he who has himself labored to improve on Goodwin can adequately realize the clarity and compactness of his statements that never err through undue emphasis either on logical or on æsthetic relations.

The very excellence and success of Goodwin's work in the department of grammar made the wider public, and to a certain degree even the Hellenists of this country, ignorant of the scope and the distinction of his work in other fields. It is an altogether erroneous notion that Goodwin was purely a grammarian, honorable as

that title has been made by many illustrious scholars. The range of his sympathies with Greek literature was indicated early in his career. The Greek grammar appeared in 1870; in the same year was published Goodwin's revision, in five volumes, of the translation of Plutarch's "Morals" made by various hands in the seventeenth century. Innumerable errors and infelicities of the old translation were cleared away by Goodwin, whose work was termed a "vindication" of Plutarch by Emerson, who contributed an Introduction to the revision. English readers who would acquaint themselves with the deep and broad humanity of the sage of Chæronea, in whom the intellect was illuminated by the force of morals, will long continue to use the translation of the Cambridge scholar.

With Greek philosophy Goodwin never claimed the intimate acquaintance of the professional philosopher. The temper of his mind was not metaphysical. Yet he had a large knowledge of the great ethical books of Greek literature, and years of close study made him a wise and judicious interpreter of the "Republic" of Plato and of Aristotle's "Ethics." To the investigation of the history, antiquities, and law of ancient Greece he brought a mind keenly observant of the similarities and differences between ancient and modern times. It is in the interpretation of the masterpiece of Greek oratory that the scholar must be able to draw, in well-nigh equal measure, upon a sound knowledge of ancient history and ancient law. Goodwin's mastery of this double field appears in his editions of Demosthenes' "On the Crown" (1901) and "Against Midias" (1906). He wrote also on "The Relation of the πρόεδροι to the πρυτάνεις in the Athenian Senate" (*Transactions of the American Philological Association*, Vol. 16, 1885), and on "The Value of the Attic Talent in Modern Money" (*o. c.* Vol. 16).

It is to be regretted that Goodwin would not allow himself to be persuaded to give to the world an edition of Æschylus, to the interpretation of whose text he devoted years of profound study. He edited the text and prepared a translation of the "Agamemnon," to be used in connection with the public presentation of that play by the Department of Classics at Harvard in 1906. Of his critical method we have a luminous example in the paper entitled "On the

Text and Interpretation of certain passages in the Agamemnon of Æschylus" (*Transactions Amer. Philol. Assoc.*, Vol. 8, 1877). In confronting the great difficulties of the text of Æschylus, Goodwin was invariably hostile to the sciolist who complacently substitutes his emendations for the words of the poet. "Est quaedam etiam nesciendi ars et scientia"—an admonition applied far more rigorously by the American scholar than by its German author.

In common with many men of his position Goodwin turned at times to editorial work of a humbler character. He reëdited Felton's editions of Isocrates' "Panegyricus" (1863) and the "Birds" (1868) and "Clouds" (1870) of Aristophanes. One of the most excellent books of its kind is the "Greek Reader" (1877, and in many later editions), while his edition of the "Anabasis" (1885 ff.), prepared in conjunction with one of his colleagues, Professor J. W. White, is a model for its exact attention to grammatical details.

It was Goodwin's good fortune to visit Greece as a young man when fresh from his studies in Germany; and it was he who was the first director of the American School of Classical Studies at Athens (1882–83), an appropriate honor for the foremost Greek scholar of his time who was also one of the founders of the American Institute of Archæology. To his acquaintance with the land of Greece, reinforcing his knowledge of Greek literature and history, we owe the admirable paper on "The Battle of Salamis," first published in 1885 and in another form in 1906. Goodwin's careful sifting of the evidence determined the several localities in question and convincingly described the dispositions and movements of the Greek and barbarian forces in connection with that memorable contest. His interest in the land of Greece was fittingly signalized by his being named a knight of the Greek Order of the Redeemer.

Such are the landmarks in the career of a scholar whose life was spent in quiet devotion to high things, a life that made no parade and sought none of the noisy ways of fame. Yet to few Americans of our time has been given an ampler measure of the tribute of recognition that great powers have been used effectively and serviceably. Goodwin's mastery of Greek syntax enfranchised in Great Britain the Hellenic scholarship of the United States. The "Moods

and Tenses" became there, as at home, a standard treatise; the *Journal of Philology* and Liddell and Scott's Greek Lexicon contain evidences of his exact learning. He received the degree of LL.D. from Cambridge in 1883, from Edinburgh in 1890, and the degree of D.C.L. from Oxford also in 1890. In 1905 Göttingen renewed *honoris causa* the degree of Ph.D. which he had received at that University in 1855. At home he received honorary degrees from Amherst, Chicago, Columbia, Yale, and Harvard. He enjoyed the rare distinction of being twice president of the American Philological Association (1871 and 1884); he was vice-president of the Egypt Exploration Fund; for many years he was closely identified with the work of the Archæological Institute of America; and he held the office of president of the American Academy of Arts and Sciences in 1903. He was an honorary member of the Hellenic Society of London, of the Philological Society of Cambridge, England, of the Hellenic Society of Constantinople, of the Archæological Society and Academy of Science at Athens, and was a foreign member of the Imperial German Archæological Institute.

Professor Goodwin was not a blind worshipper of the classical literature of the ancients; he saw in it, not an agent for the discipline of the intellect of all youth, but an instrument, imperative for the understanding of the development of European letters, and salutary for those who would deepen their appreciation of English literature. In him the intellectual spirit of scientific research in the field of grammar did not blunt the literary and artistic sense, which, as has well been said, is partly also moral. The old-time humanities translated themselves in him into the spirit of just and refined living. He did not confine his sympathies to the ancient world that was his by the association of daily work; but he realized, in the words of Renan, that "progress will eternally consist in developing what Greece conceived"; and from Greece he gathered, what many of the noblest and best have gathered thence, a large part of that wisdom of life which is more precious and more enduring than mere learning.

HERBERT WEIR SMYTH.

MINUTES.

MINUTES.

Stated Meeting January 3, 1913.

William W. Keen, M.D., LL.D., President, in the Chair.

Thanks were received from the Naturwissenschaftliche Verein für Steiermark for the Society's friendly good wishes upon the occasion of, and for the sending of a delegate to, its Semi-Centenary.

Professor Herbert Weir Smyth presented an obituary notice of Professor William Watson Goodwin.

The following papers were read:

"The Historic Value of Old Law Books," by Hampton L. Carson, Esq.

"Place and Personal Names of the Gosiute Indians of Utah," by Ralph V. Chamberlin (introduced by the Secretaries).

The Judges of the Annual Election of Officers and Councillors held on this day between the hours of two and five in the afternoon, reported that the following named members were elected, according to the Laws, Regulations and Ordinances of the Society, to be the officers for the ensuing year:

President,

William W. Keen.

Vice-Presidents,

William B. Scott,
Albert A. Michelson,
Edward C. Pickering.

Secretaries,

I. Minis Hays,
Arthur W. Goodspeed,
Amos P. Brown,

Harry F. Keller.

Curators,

Charles L. Doolittle,
William P. Wilson,
Leslie W. Miller.

Treasurer,

Henry La Barre Jayne.

Councillors

(To serve for three years),

Charlemagne Tower,
William Morris Davis,
George Ellery Hale,
R. A. F. Penrose, Jr.

(To fill an unexpired term),

Samuel W. Pennypacker.

Stated Meeting February 7, 1913.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

The death was announced of George Augustus Koenig, A.M., Ph.D., at Philadelphia, on January 14, 1913, æt. 69.

Dr. Paul Heyl (introduced by Professor Harry F. Keller) read a paper on "Platinum in North Carolina," which was discussed by Professor Keller.

Stated Meeting March 7, 1913.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

An invitation was received from the President and Executive Committee of the Twelfth International Geological Congress, inviting the Society to be represented at the Congress to be held in Canada in the month of August.

Dr. R. M. Pearce (introduced by Dr. W. W. Keen) read a paper on "The Gradual Development of the Idea of Cellular Structure throughout the Animal and Vegetable Kingdom," which was discussed by Dr. Coplin, Dr. Tyson, Professor Kraemer, Dr. Hawke, Dr. Donaldson and Dr. Harshberger.

The following Address was adopted:

To His Excellency
Woodrow Wilson,

Sir: The American Philosophical Society extends its cordial congratulations to you, as one of its fellow members, upon your accession to the Presidency of the United States. You carry into public life the ideals of the scholar and you will show in the new world, as has been proved so often in the old, that scientific training in the best and broadest sense of the term, is a help to the practical statesman. Your studies in history and political science will illuminate your task of giving to the Nation a wise and strong government.

It was Montesquieu, the good genius of the makers of our National Constitution, who said that for a safe voyage of the Ship of State the spirit of the laws should serve as compass and history should be the chart. This Society confidently believes that you have at your command this compass and this chart; that with your firm hand at the helm the Ship of State will safely ride the seas, and that, like those of your distinguished predecessors in the Presidency, who were its members, you will help to make the future history of the Nation worthy of its past.

Seven times since the founding of the Republic the American Philosophical Society has had cause for congratulation in the selection of one of its members as President of the United States. Washington, Adams, Jefferson, Madison, the second Adams, Buchanan and Grant were all honored names upon its Roll before the popular vote inscribed them in the list of American Presidents. To you, the eighth in turn of its members to enter upon this high office, this Society extends its warmest greeting.

Given under the Seal and in the name of The American Philosophical Society held at Philadelphia for Promoting Useful Knowledge, this seventh day of March, 1913.

Stated Meeting April 4, 1913.

William W. Keen, M.D., LL.D., President, in the Chair.

The following letter was received from President Wilson in response to the address presented to him by the Society on March 19:

THE WHITE HOUSE,

WASHINGTON, March 19, 1913.

My dear Dr. Keen: May I not express to you, and through you to the members of the American Philosophical Society, my deep and sincere appreciation of the cordial message brought me from the Society by you and your associates this afternoon? Nothing has gratified me more. I do not know of any Association whose confidence I would rather enjoy. It has been a matter of peculiar pride to me to be associated with the American Philosophical Society, and that that distinguished body should feel honored by my elevation to the Presidency is a source of genuine satisfaction to me. I can only say in reply to their gracious Address that I shall hope and strive at all times to deserve their respect and confidence.

Cordially and sincerely yours,

WOODROW WILSON.

The decease of the following members was announced:

Professor Angelo de Gubernatis, at Rome, on February 27, 1913; æt. 73.

John Shaw Billings, M.D., LL.D., Dc.L., at New York, on March 10, 1913; æt. 74.

Edward Pepper, LL.D., at Algiers, on March 23, 1913; æt. 66.

James McCrea, at Ardmore, Pa., on March 28, 1913; æt. 65.

The following papers were read:

"Illuminants Present and Future," by Herbert E. Ives, Ph.D. (introduced by Dr. W. W. Keen), which was discussed by Professor Ferree.

"The Fluting and Pitting of Granites in the Tropics," by John C. Branner, Ph.D., LL.D.

"The True Atomic Weight of Bromine," by Gustavus Hinrichs (Introduced by Professor Keller).

General Meeting April 17, 18, and 19, 1913.

Thursday, April 17. Opening Session—2 o'clock.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

Professor J. C. Kapteyn, elected to membership in 1907, signed the roll and was admitted into the Society.

An invitation was received from the Missouri Botanical Society

to be represented at the opening of its new hall on May 1 and 2, and Professor Francis E. Nipher was appointed to represent the Society on the occasion.

The following papers were read:

"The Biographies of Suetonius," by John C. Rolfe, Ph.D., Professor of the Latin Language and Literature, University of Pennsylvania.

"The Etymology of the Word 'Ill,'" by Hermann Collitz, Ph.D., Professor of Germanic Philology, Johns Hopkins University.

"The Treaty Obligations of the United States relating to the Panama Canal," by Charlemagne Tower, A.B., LL.D., Philadelphia.

"A Counsel of Perfection. A Plan for a State University and for an Automatic Collection and Distribution of a State Tax for Higher Education," by Joseph G. Rosengarten, A.M., LL.D., Philadelphia. Discussed by Dr. Cyrus Adler.

"Reprisals, Contraband and Piracy under Queen Elizabeth," by Edward P. Cheyney, A.M., LL.D., Professor of European History, University of Pennsylvania. Discussed by Mr. Harrison S. Morris and Mr. Rosengarten.

"Some Commercial Transactions in Babylonia During the Period of Greek Supremacy," by Albert T. Clay, A.M., Ph.D., Laffan Professor of Assyriology and Babylonian Literature, Yale University.

"The Historical Value of the Patriarchal Narratives," by George A. Barton, A.M., Ph.D., Professor of Semitic Languages, Bryn Mawr College.

"The Succession of Human Types in the Glacial and Interglacial Epochs of the European Pleistocene," by Henry Fairfield Osborn, D.Sc., LL.D., Research Professor of Paleontology, Columbia University, New York.

"The Flora of Bermuda" (illustrated), by Stewardson Brown, Conservator, Botanical Section, Academy of Natural Sciences of Philadelphia (introduced by Professor Henry Kraemer).

"A New Type of Sewage Disposal Tank," by William Pitt

Mason, M.D., LL.D., Professor of Chemistry, Rensselaer Polytechnic Institute, Troy, N. Y.

"Determination of Uranium and Vanadium in Carnotite Ores of Colorado," by Andrew A. Blair, Philadelphia.

Friday, April 18. Morning Session—9.35 o'clock.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

The following papers were read:

"The Uses and Needs of Selachology (The Study of Sharks and Rays)," by Burt G. Wilder, M.D., Emeritus Professor of Neurology and Vertebrate Zoology, Cornell University.

"Interpretations of Brain Weight" (illustrated), by Henry H. Donaldson, Ph.D., D.Sc., Professor of Neurology at The Wistar Institute of Anatomy and Biology, Philadelphia.

"The Correlation of Structural Development and Function in the Growth of the Vertebrate Nervous System" (illustrated), by George E. Coghill, Ph.D., Professor of Zoölogy, Denison University, Granville, Ohio (introduced by Dr. H. H. Donaldson).

"The Correlation of Structure and Function in the Development of the Nervous System" (illustrated), by Stewart Paton, M.D., Lecturer in Biology, Princeton University (introduced by Dr. A. C. Abbott).

"The Relation Between the Physical State of the Brain Cells and Brain Function (experimental and clinical)," by George W. Crile, M.D., Ph.D., Professor of Clinical Surgery, Western Reserve University, Cleveland. Discussed by Professor Conklin, Dr. Paton, Dr. Minot and Professor Nipher.

"Life of Cells Outside the Organism" (illustrated), by Ross G. Harrison, M.D., Ph.D., Professor of Comparative Anatomy, Yale University (introduced by Dr. A. C. Abbott). Discussed by Dr. Crile and Dr. Donaldson.

"Heredity and Selection," by William E. Castle, Ph.D., Professor of Zoölogy, Harvard University.

"The Nature of Sex and the Method of Its Determination"

(illustrated), by Clarence E. McClung, A.M., Ph.D., Professor of Zoölogy, University of Pennsylvania (introduced by Dr. George A. Piersol). Discussed by Dr. Minot.

"Fever: Its Nature and Significance," by Victor C. Vaughan, M.D., LL.D., Professor of Hygiene and Physiological Chemistry, University of Michigan. Discussed by Dr. Wilder.

"The Control of Typhoid Fever by Vaccination," by Mazÿck P. Ravenel, M.D., Professor of Bacteriology, University of Wisconsin.

Afternoon Session—2 o'clock.

William B. Scott, Ph.D., Sc.D., LL.D., Vice-President, in the Chair.

The following papers were read:

"Gautemala and the Highest Native American Civilization," by Ellsworth Huntington, M.A., Ph.D., Assistant Professor of Geography, Yale University (introduced by Mr. Henry G. Bryant). Discussed by Professor Scott and Mr. Joseph Willcox.

"Further Considerations on the Origin of the Himalaya Mountains and the Plateau of Tibet," By T. J. J. See, A.M., Ph.D., U. S. Naval Observatory, Mare Island, Cal.

"Dana's Contribution to Darwin's Theory of Coral Reefs," by William Morris Davis, Sc.D., Ph.D., Sturgis-Hooper Professor of Geology, Emeritus, Harvard University. Discussed by Professor Scott.

"The Formation of Coal Beds," by John J. Stevenson, A.M., LL.D., Emeritus Professor of Geology, University of the City of New York.

"Cambrian Fossils from British Columbia" (illustrated), by Charles D. Walcott, Ph.D., Sc.D., LL.D., Secretary of the Smithsonian Institution.

"The Alleghenian Divide and Its Influence Upon Fresh Water Faunas," by Arnold E. Ortmann, Ph.D., Sc.D., Curator of Invertebrate Zoölogy, Carnegie Museum, Pittsburgh. Dis-

cussed by Mr. Joseph Willcox and Professor W. M. Davis.

"Neutralization and Elimination of Toxic Substances," by Oswald Schreiner, Ph.D., Chief of Division of Soil Fertility Investigations, Department of Agriculture, Washington. Discussed by Dr. Harshberger and Professor Nipher.

"Progressive Evolution Among Hybrids of Oenothera" (illustrated), by Bradley M. Davis, A.M., Ph.D., Assistant Professor of Botany, University of Pennsylvania (introduced by Professor John M. Macfarlane).

"Climatic Areas of the United States as Related to Plant Growth" (illustrated), by Burton E. Livingston, Ph.D., Professor of Plant Physiology, Johns Hopkins University (introduced by Professor John W. Harshberger). Discussed by Dr. Harshberger, Professor Scott, and Professor Nipher.

"The Day of the Last Judgment," by Paul Haupt, Ph.D., LL.D., Professor of Semitic Languages, Johns Hopkins University.

"On the Character and Adventures of Mūladora," by Maurice Bloomfield, Ph.D., LL.D., Professor of Sanskrit and Comparative Philology, Johns Hopkins University.

Evening Session.

George Grant MacCurdy, A.M., Ph.D., Assistant Professor of Archæology, Yale University, gave an illustrated lecture on "The Antiquity of Man in the Light of Recent Discoveries."

Saturday, April 19.

Executive Session—9.30 o'clock.

William W. Keen, M.D., LL.D., President, in the Chair.

Pending nominations for membership were read and the Society proceeded to an election.

Secretary Keller and Professor Rolfe served as tellers and reported that the following nominees had been elected to membership:

Residents of the United States

George Francis Atkinson, Ph.D., Ithaca, N. Y.
Charles Edwin Bennett, A.B., Litt.D., Ithaca, N. Y.
John Henry Comstock, B.S., Ithaca, N. Y.
Reginald Aldworth Daly, Boston, Mass.
Luther Pfahler Eisenhart, Princeton, N. J.
George W. Goethals, Culebra, Canal Zone.
William C. Gorgas, M.D., Sc.D., LL.D., Ancon, Canal Zone.
Ross G. Harrison, A.B., Ph.D., M.D., New Haven, Conn.
George Augustus Hulett, Princeton, N. J.
Clarence E. McClung, A.M., Ph.D., Swarthmore, Pa.
John Dyneley Prince, Ph.D., Sterlington, N. Y.
Samuel Rea, Sc.D., Bryn Mawr, Pa.
Henry Norris Russell, Ph.D., Princeton, N. J.
Charles Schuchert, New Haven, Conn.
Witmer Stone, A.M., Philadelphia.

Foreign Residents.

Sir Arthur John Evans, D.Litt., LL.D., F.R.S., Oxford, Eng.
Sir Joseph Larmor, D.Sc., LL.D., F.R.S., Cambridge, Eng.
Arthur Schuster, Sc.D., Ph.D., F.R.S., Manchester, Eng.

Morning Session—10 o'clock.

EDWARD C. PICKERING, D.Sc., LL.D., F.R.S., Vice-President, in the Chair.

The following papers were read:

"The Potassium, Phosphorus, Nitrogen Cycles," by Charles E. Munroe, Ph.D., LL.D., F.C.S., Professor of Chemistry, George Washington University, Washington.

"An Ammonia System of Acids, Bases and Salts," by Edward C. Franklin, Chief of Division of Chemistry, U. S. Public Health and Marine Hospital Service. Discussed by Dr. H. C. Jones and Professor H. F. Keller.

"Some Unsolved Problems in Radio-activity" (illustrated), by

William Duane, Ph.D., late of the Curie Radium Laboratory, University of Paris (introduced by Professor Arthur W. Goodspeed). Discussed by Dr. H. C. Jones, Mr. E. C. Franklin and Mr. Joseph Willcox.

"Some Diffraction Phenomena; Superposed Fringes," by Charles F. Brush, Ph.D., LL.D., Cleveland, O.

"Matter in its Electrically Explosive State," by Francis E. Nipher, A.M., LL.D., Professor of Physics, Washington University, St. Louis.

"New Investigations of Resonance Spectra," by Robert Williams Wood, A.B., LL.D., Professor of Experimental Physics, Johns Hopkins University. Discussed by Professor Schuster.

"Application of Recent Studies on the Origin of the Earth's Magnetic Field to the Possible Magnetic Fields of Rotating Bodies in General" (illustrated), by Louis A. Bauer, Ph.D., Director of the Department of Terrestrial Magnetism of the Carnegie Institution, Washington.

"The Determination of Visual Stellar Magnitudes by Photography," by Edward C. Pickering, D.Sc., LL.D., F.R.S., Director of the Harvard College Observatory, Cambridge.

"Some Problems in Connection with the Milky Way, as Shown by Photographs Made with Portrait Lenses," by Edward E. Barnard, Sc.D., LL.D., Astronomer of the Yerkes Observatory, Williams Bay, Wis.

"The Spectroscopic Detection of the Rotation Period of Uranus," by Percival Lowell, LL.D., and V. M. Slipher, Ph.D., of the Lowell Observatory, Flagstaff, Arizona.

"On the Spectrum of the Nebula in the Pleiades," by V. M. Slipher, Ph.D., of the Lowell Observatory, Flagstaff, Arizona.

"Eclipsing Variable Stars," by Henry Norris Russell, Ph.D., Professor of Astronomy and Director of the Observatory, Princeton University (introduced by Professor William F. Magie).

"Progress of New Lunar Tables," by Ernest W. Brown, M.A., Sc.D., F.R.S., Professor of Mathematics, Yale University.

Dr. John Mason Clarke, elected to membership in 1911, Dr. E. C.

Franklin, elected in 1912, and Professor Henry Norris Russell, a newly elected member, subscribed the laws and were admitted into the Society.

Afternoon Session—2 o'clock.

EDWARD C. PICKERING, D.Sc., LL.D., F.R.S., Vice-President, in the Chair.

A portrait of William W. Keen, M.D., LL.D., President of the Society, was presented by Joseph G. Rosengarten, A.M., LL.D., on behalf of the subscribers.

Mr. Chairman and Members:

On behalf of the subscribers, I have the honor and privilege of presenting to the Society, the portrait of our President, Dr. William W. Keen, by Robert Vonnoh.

Among the one hundred and twenty-nine subscribers,—a list will be handed to the Secretaries for preservation among its records, will be found the names of many representatives of institutions of learning, many men noted in science and letters, who thus testify their grateful sense of Dr. Keen's great services to the Philosophical Society, both as member and as President.

His portrait is that of the seventeenth President, thus adding one more to the long series that adorn this hall, beginning with the first president, Hopkinson, followed by Franklin, Jefferson, Rittenhouse, Wistar, the two Pattersons, father and son, Tilghman, Chapman, the two Baches, Kane, Wood, Fraley, the second Wistar, Edgar F. Smith, and now Keen.

This portrait represents Dr. Keen seated in Franklin's chair, and in the cap and gown of the University of St. Andrews, for both Franklin and Keen were the recipients of its Doctor's degree.

Of Dr. Keen's distinguished career, it is enough to say that a graduate of Brown University in 1859, he is also a Trustee and Fellow, as well as the recipient from that University, and from Toronto and Yale and Greifswald and Upsala and St. Andrews, of their highest academic honors.

His services as a surgeon in the Civil War covered nearly the whole period of that struggle.

His work as a teacher began in the Philadelphia School of Anatomy in 1866, and ended only when he resigned in 1907, after long and brilliant service in Jefferson Medical College.

His contributions to medical and general literature have won for him a place among our authors.

Retired from the active practice of his profession, with the grateful acknowledgments and regrets of his colleagues, his students and his patients, he has given time and thought to his duties as President of the American Philosophical Society.

In acknowledgment of his great service in that office, his fellow members, and some not members of the Society, join in presenting his portrait to the Philosophical Society that it may take its place on the walls of this Hall, with the long list of the portraits of his predecessors.

By his services to the world and to the Society, he has won the affection and esteem typified in the portrait now presented to the Society.

The portrait was accepted on behalf of the Society by Vice-President Pickering, who said:

To render a scientific society successful, it is necessary that at least two or three of its members should devote a large part of their time and energy to its administration. Even then it is not easy to secure an annual meeting which many regard as the most interesting of its kind in the country. While it is eminently fitting that the oldest scientific society of America should maintain this position, those of us who see something of the management each year, realize how largely this is due to the successful administration of our seventeenth President, supported as he is by the unwearied efforts of other officers of the Society. This painting will always serve as a reminder of the able and tactful services of Dr. Keen.

The annual meetings are remarkable not only for the high grade of the papers presented but, what is unusual, for their interest to specialists in other departments of human knowledge. For this

reason, many of us come hundreds of miles to meet our fellow members here.

By the authority and in the name of the American Philosophical Society held at Philadelphia for Promoting Useful Knowledge, I accept this gift with grateful acknowledgments and the hope that it may be many years before we are obliged to elect the eighteenth President of the Society.

Dr. Arthur Schuster, Dr. Ross G. Harrison and Professor Clarence E. McClung, newly elected members, subscribed the laws and were admitted into the Society.

The following papers were read:

"Symposium on Wireless Telegraphy, Radiated and Received Energy," by Lewis W. Austin, Ph.D., Head of U. S. Naval Radio-Telegraph Laboratory, Bureau of Standards, Washington (introduced by Professor William F. Magie).

"Resonance in Radiotelegraphic Receiving Stations," by George W. Pierce, A.M., Ph.D., Assistant Professor of Physics, Harvard University (introduced by Professor Arthur W. Goodspeed).

"New Form of Resonance Circuits," by Michael I. Pupin, Ph.D., Sc.D., Professor of Electro-Mechanics, Columbia University, N. Y.

"The International Radiotelegraphic Conference of London and its Work," by Arthur Gordon Webster, Ph.D., LL.D., Professor of Physics and Director of the Physical Laboratory, Clark University, Worcester.

Stated Meeting May 2, 1913.

William W. Keen, M.D., LL.D., President, in the Chair.

Dr. Witmer Stone, a newly elected member, subscribed the laws and was admitted into the Society.

Acknowledgment of election to membership was received from

George Francis Atkinson, Ph.D., Ithaca, N. Y.

Charles Edwin Bennett, A.B., Litt.D., Ithaca, N. Y.

John Henry Comstock, B.S., Ithaca, N. Y.

Reginald Aldworth Daly, Boston, Mass.

Luther Pfahler Eisenhart, Princeton, N. J.

George Augustus Hulett, Princeton, N. J.

John Dyneley Prince, Ph.D., Sterlington, N. Y.

Samuel Rea, Sc.D., Bryn Mawr, Pa.

Witmer Stone, A.M., Philadelphia.

Obituary notices of Horace Howard Furness, Litt.D., LL.D., by Professor F. E. Schelling, His Excellency M. Jusserand, Dr. Le-Baron Briggs, Dr. Morris Jastrow, Jr., and Mr. Owen Wister were read.

The decease was announced of Lester F. Ward, A.M., LL.D., at Washington, April 18, 1913; æt. 72.

The application of the cinematograph to studies in biology was demonstrated by Professor A. W. Goodspeed, Dr. W. M. L. Coplin and Dr. A. P. Brubaker, and was discussed by Dr. Keen.

Stated meeting October 3, 1913.

William W. Keen, M.D., LL.D., President, in the Chair.

Letters accepting membership were received from:

Sir Joseph Larmor

Prof. Arthur Schuster

Prof. Charles Schuchert

Col. George W. Goethals

Dr. William C. Gorgas

Prof. Reginald A. Daly

Sir Arthur John Evans.

Invitations were received:

From the Director of the Imperial Botanical Garden of St. Petersburg to the Bi-Centennial Jubilee of the founding of the Garden, on June 21–25, 1913.

From the Directors and Faculty of Ursinus College to the inauguration of George Leslie Omwake, as President, on October 7th.

From the President, Trustees and Faculty of Princeton University to the dedication of the Graduate College, on October 22d.

The decease of the following members was announced:

William Hallock, Ph.D., at Providence, R. I., on May 20, 1913, æt. 56.

Rt. Hon. John Lubbock, Lord Avebury, D.C.L., LL.D., F.R.S., on May 28, 1913, æt. 79.

Philip Lutley Sclater, M.A., D.Sc., at Odiham Priory, Winchfield, Hants, Eng., on June 27, 1913, æt. 83.

Charles H. Cramp, A.B., Sc.D., at Philadelphia, on June 6, 1913, æt. 85.

Horace Jayne, M.D., Ph.D., at Wallingford, Pennsylvania, on July 8, 1913, æt. 54.

William Tatham, at Paris, on September 10, 1913, æt. 63.

William Armstrong Ingham, C. E., at Philadelphia, on September 23, 1913, æt. 87.

The following papers were read:

"Factors in the Exchange Value of Meteorites," by Warren M. Foote. (Introduced by Prof. Harry F. Keller.)

"The Nomenclature of Minerals," by Austin F. Rogers. (Introduced by Prof. John C. Branner.)

"The Marine Tertiary Stratigraphy of the North Pacific Coast of America," by Ralph C. Arnold and Harold Hannibal. (Introduced by Prof. John C. Branner.)

"Geology of the Region about Natal, Rio Grande do Norte, Brazil," by Olaf Pitt Jenkins. (Introduced by Prof. John C. Branner.)

Stated Meeting November 7, 1913.

William W. Keen, M.D., LL.D., President, in the Chair.

The decease was announced of

Sir William Henry Preece, K.C.B., at London, on November 6, 1913, in his eightieth year.

Alfred Russell Wallace, O.M., LL.D., D.C.L., at Broadstone, Wimborne, Eng., on November 7, 1913, in his ninety-first year.

Prof. John M. Macfarlane read a paper "On the Phylogeny of Plants in Relation to their Environment."

Stated Meeting December 5, 1913.

William W. Keen, M.D., LL.D., President, in the Chair.

The decease was announced of Sir Robert Stawell Ball, Kt., M.A., LL.D., F.R.S., at Cambridge, England, on November 26, 1913, æt. 73.

Dr. Simon Flexner read a paper on "Epidemiology of Disease with Special Reference to Infantile Paralysis."

The President read his "Annual Address."

INDEX

(176)